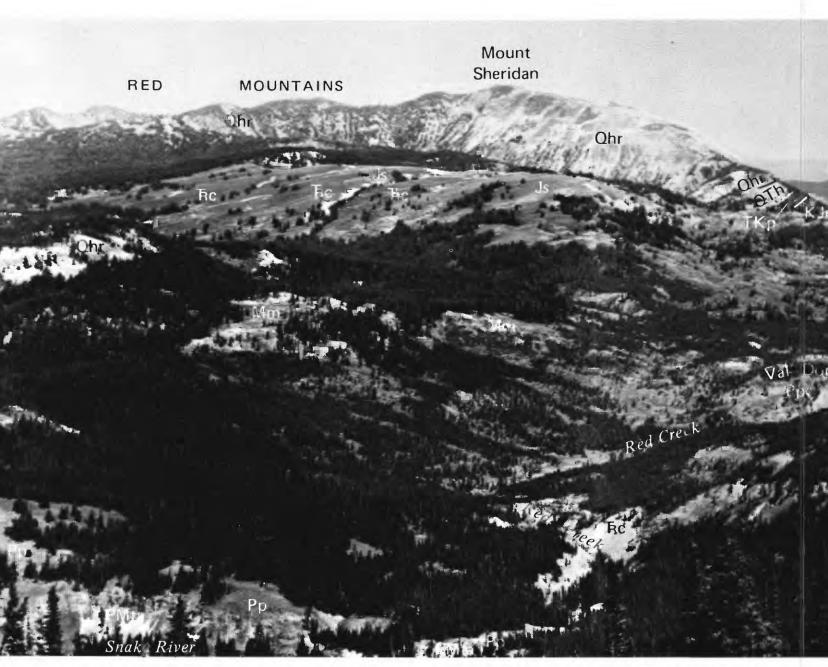
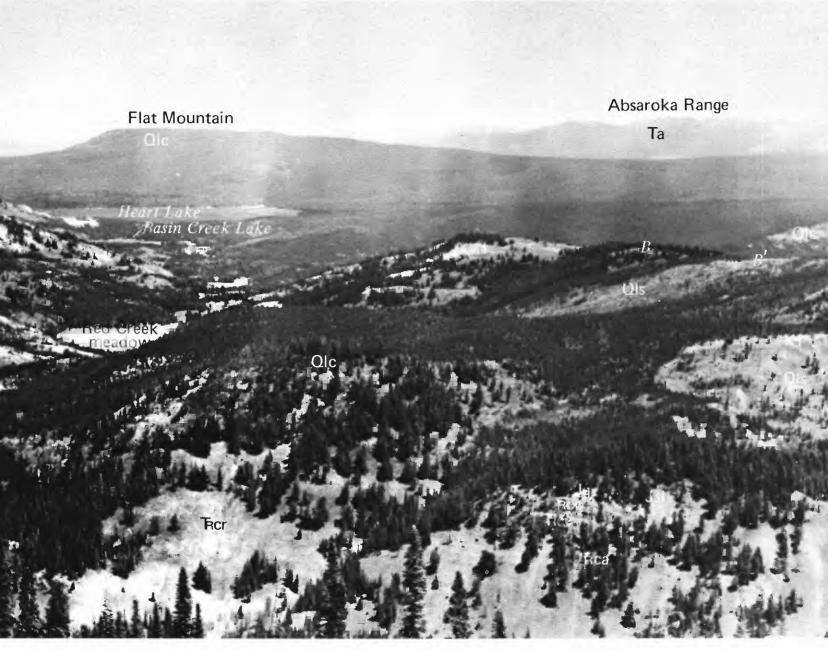


GEOLOGY OF SEDIMENTARY ROCKS IN SOUTHERN YELLOWSTONE NATIONAL PARK, WYOMING



FRONTISPIECE.—Telephoto panorama showing the sedimentary rocks, their relation to the Pleistocene rhyolitic welded Park. This view is northeast from about 1 mile north-northeast of milepost 15 on the southern boundary of the Madison Limestone; IPMta, cliff and slope of Pennsylvanian Tensleep Sandstone and Pennsylvanian and Mississiptree growth, and Ppc, chert beds arched into a dome—for the last quarter century or more called Val Dome in ice, and its members that are described in the Snake River measured section 2 miles from the camera point— Rcp cliff of Popo Agie Member; Jg, Jurassic Gypsum Spring Formation; Js, Jurassic Sundance Formation, Morrison(?) Formations, Kf, Upper Cretaceous Frontier Formation at approximate site of large fossil collection Absaroka Volcanic Supergroup; QTn, Pleistocene or Pliocene Heart Lake Conglomerate (type section); Qhr, Pleistolandslides in Cretaceous shales. A, site of measured section of Jurassic rocks east of Red Creek meadow, described in text.



tuffs, and their structure along the south and southeast sides of the Basin Creek uplift in southern Yellowstone National park; Mount Sheridan is 9 miles from the camera point. Photograph by J. D. Love, July 29, 1972. Mm, Mississippian pian Amsden Formation; Pp, Permian Phosphoria Formation and related rocks, showing characteristically patchy honor of a lady by that name; \mathbf{k}_{C} , Triassic Chugwater Formation, with surface fluted by southwestward-moving \mathbf{k}_{C} , Red Peak Member, \mathbf{k}_{C} , Alcova Limestone Member, \mathbf{k}_{C} , cliff of Crow Mountain Sandstone Member, and characteristically devoid of trees, and \mathbf{j}_{S} , its lower part; \mathbf{k}_{S} , Lower Cretaceous and Upper Jurassic Cloverly and described in text; \mathbf{T}_{K} , Paleocene and Upper Cretaceous Pinyon Conglomerate; \mathbf{T}_{a} , volcaniclastic rocks of the Eocene cene Huckleberry Ridge Tuff; \mathbf{Q}_{C} , Pleistocene Lava Creek Tuff on west wall of Heart River Canyon; \mathbf{Q}_{S} , large Quaternary in text; \mathbf{B} - \mathbf{B}' , site of measured section of Lower Cretaceous rocks south-southeast of Red Creek meadow, described

Geology of Sedimentary Rocks in Southern Yellowstone National Park, Wyoming

By J. D. LOVE and W. R. KEEFER

GEOLOGY OF YELLOWSTONE NATIONAL PARK

GEOLOGICAL SURVEY PROFESSIONAL PAPER 729-D

Prepared in cooperation with the National Park Service, the Geological Survey of Wyoming, and the Department of Geology of the University of Wyoming



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Yellowstone National Park, the oldest of the areas set aside as part of the national park system, lies amidst the Rocky Mountains in northwestern Wyoming and adjacent parts of Montana and Idaho. Embracing large, diverse, and complex geologic features, the park is in an area that is critical to the interpretation of many significant regional geologic problems. In order to provide basic data bearing on these problems, the U.S. Geological Survey in 1965 initiated a broad program of comprehensive geologic and geophysical investigations within the park. This program was carried out with the cooperation of the National Park Service, and was also aided by the National Aeronautics and Space Administration, which supported the gathering of geologic information needed in testing and in interpreting results from various remote sensing devices. This professional paper chapter is one of a series of technical geologic reports resulting from these investigations.

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GEOLOGY OF YELLOWSTONE NATIONAL PARK

GEOLOGY OF SEDIMENTARY ROCKS IN SOUTHERN YELLOWSTONE NATIONAL PARK, WYOMING

By J. D. Love and W. R. Keefer

ABSTRACT

Sedimentary rocks ranging in age from Devonian to Holocene are exposed within an area of about 100 square miles in southern Yellowstone National Park where the original cover of volcanic rocks has been stripped away by erosion. These sedimentary rocks, and the structural features that involve them, have not previously been described in detail. The stratigraphic occurrence and identifications of genera and species of fossils in more than 25 collections are given.

Precambrian pink granite, various types of metamorphic rocks, Cambrian sandstone and limestone and Bighorn Dolomite (Ordovician), none of which is presently exposed, are nevertheless represented by abundant, locally derived boulders in Eocene conglomerates. Generalized lithology and representative thicknesses of exposed rock units are Darby Formation (Devonian), fetid brown dolomite and yellow and red shale, 250 feet; Madison Limestone (Mississippian), blue-gray cliff-forming limestone, 1,100 feet; Amsden Formation (Mississippian and Pennsylvanian), gray limestone and red and green shale, with Darwin Sandstone Member at base, 230 feet; Tensleep Sandstone (Pennsylvanian), white to buff hard sandstone, 380 feet; Phosphoria Formation and related rocks (Permian), dark-gray to brown sandy dolomite, sandstone, and chert, and black phosphorite and shale, 200 feet; Dinwoody Formation (Triassic), drab hard slabby dolomitic siltstone, 200 feet; Chugwater Formation (Triassic), red shale, siltstone, and sandstone, 1,000 feet; Gypsum Spring Formation (Middle Jurassic), white gypsum, red shale, and gray thin beds of dolomite, 50 feet; Sundance Formation (Middle and Upper Jurassic), gray limy nonglauconitic shale and limestone overlain by highly glauconitic limy sandstone, 450 feet; Morrison(?) and Cloverly Formations undivided (Upper Jurassic and Lower Cretaceous), variegated claystone and white to brown quartzitic sandstone beds, 600 feet; Thermopolis Shale (Lower Cretaceous), black shale member 170 feet thick overlain by gray quartzitic Muddy Sandstone Member, 100 feet thick; Mowry Shale (Lower Cretaceous), silvery gray siliceous shale, thin bentonite and thin tuffaceous siliceous sandstone beds, 650 feet; Frontier Formation (Upper Cretaceous), gray sandstone, and gray to black shale, with white bentonite and porcellanite beds in lower part, 850 feet; Cody Shale (Upper Cretaceous), gray soft shale with a persistent glauconitic gray sandstone bed in upper middle, 1,750 feet; Bacon Ridge Sandstone (Upper Cretaceous), gray fossiliferous marine sandstone, 500-1,700 feet; Harebell Formation (Upper Cretaceous), drab to green tuffaceous sandstone, siltstone, and claystone, and lenticular quartzite pebble conglomerates, 0-9,000 feet; Pinyon Conglomerate (Upper Cretaceous and Paleocene), quartzite boulder conglomerate, brown, 0-450 feet; Langford Formation (Eocene), waterlaid gray volcanic conglomerate with abundant boulders of Precambrian igneous and metamorphic rocks, Paleozoic sedimentary rocks, and Tertiary andesite and basalt, 0-500 feet; Wiggins Formation (Eocene), pink to light-gray volcanic mudflows with

large boulders of andesite and basalt, 0–1,000 feet; White River Formation (Oligocene, present 3 miles south of the park), white tuffaceous claystone, 0–200 feet; Colter Formation (Miocene, present 3 miles south of the park), light-gray tuffaceous massive to thick-bedded soft sandstone, 0–1,000 feet; Heart Lake Conglomerate (Pliocene or Pleistocene), composed of Paleozoic limestone, Cenozoic rhyolite, talc, and chlorite fragments in light-gray matrix, 0–330 feet; Yellowstone Group (Pleistocene), purple to brown ash-flow tuff and rhyolite, 0–1,000 feet; Lewis Canyon Rhyolite (Pleistocene), lava flows, 0–500 feet. These rocks are overlain locally by thin landslide, glacial, hot spring, alluvial, and terrace deposits of Pleistocene and Holocene age.

Large northwest-trending folds and fault blocks are the dominant structural features and are grouped into four tectonic subdivisions. These are, from east to west: (1) Washakie Range, (2) Wolverine and Hancock anticlines, (3) a normal fault complex, and (4) Basin Creek uplift. The Washakie Range is a Late Cretaceous Laramide fold whose west margin is bounded by the Buffalo Fork thrust fault. In late Tertiary time, the mountain arch subsided 1,000–2,000 feet along a normal fault that coincides approximately with the older thrust trace. The Wolverine-Hancock anticlinal complex is likewise of Laramide age and consists of a major south-plunging upfolded area with a steep west flank and Cretaceous rocks exposed at the surface.

The normal fault complex between the Wolverine anticline and the Basin Creek uplift involves Paleozoic, Mesozoic, and Cenozoic rocks. Movement occurred at various times during the late Cenozoic, but much was Pleistocene. East fault blocks are generally down. Stratigraphic displacement along the East Sheridan fault, which is the largest one in this complex, may be as much as 8,000 feet.

The elliptical Basin Creek uplift first rose some 12,000–15,000 feet in Laramide time and then was eroded to Jurassic rocks before deposition of the Pinyon Conglomerate. A rejuvenation occurred in Pliocene or Pleistocene time and triggered deposition of the Heart Lake Conglomerate. Following this came much of the normal faulting, which was in part responsible for major drainage diversions and canyon cutting of the Snake River and its tributaries.

INTRODUCTION

As part of an integrated program of geological investigations in Yellowstone National Park by the U.S. Geological Survey, a study was made of the sedimentary rock terrane in the southern part of the park to: (1) determine the character, distribution, and correlation of previously undescribed sedimentary sequences; (2) delineate structural features; and (3) interpret the tectonic history. The

area of sedimentary rock exposures, approximately 100 square miles (figs. 1, 2), is bounded on the west, north, and east sides by the eroded edges of a thick blanket of volcanic rocks of early Tertiary and Quaternary ages. Structural features in the sedimentary rocks project beneath the volcanic pile for unknown distances, and some, in fact, may have once extended across the entire central region of the park and connected with structures in similar rocks that are exposed in the northern part. Particular attention was therefore focused on those structural features in the prevolcanic sedimentary rocks that may have played an important role in the development of the unusual geologic, physiographic, and thermal features now displayed in Yellowstone National Park.

During parts of the summers of 1945–49 and 1964–67, fieldwork in central-southern Yellowstone National Park was conducted by J. D. Love, assisted by H. R. Bergquist, R. K. Hose, and J. L. Weitz, as part of a broad study of regional structure and stratigraphy of northwestern Wyoming. About 30 stratigraphic sections were measured within and along the south boundary of the park, and more than 25 collections of various types of fossils were obtained. When the new program of the U.S. Geological Survey investigations in Yellowstone National Park was launched in 1966, W. R. Keefer became responsible for the study of the sedimentary rocks in this part of the park. He was assisted by M. F. Gregorich and G. O. Linkletter during the summers of 1966 and 1967.

Surface travel in the area is limited to foot and horse-back, and we wish to express our appreciation to S. O. Reynolds, A. Z. Reynolds, Emil Feuz, Rodney Pape, E. V. Simons, and John Gavin for their efficient management of tent camps and pack strings of horses in support of the field operations. Valuable logistic support was provided by helicopters, piloted by Robert Shellinger and George Duval in 1966 and 1967. We thank the personnel of the National Park Service, especially John M. Good, Chief Park Naturalist during the later years of our program, for their interest and helpful cooperation in all phases of the investigations.

The cooperation of the late S. H. Knight, D. L. Blackstone, Jr., and R. S. Houston of the Department of Geology, University of Wyoming, the late H. D. Thomas, former Wyoming State Geologist, and D. N. Miller, Jr., present State Geologist, through the years of this investigation has been of great value. Houston (1964) studied all the thin sections of igneous and sedimentary rocks collected during the 1945–49 work, and many of his descriptions are incorporated in the present report.

Field mapping was done on aerial photographs, at scales ranging from 1:37,400 to 1:62,500. The data were then transferred to a topographic base map (pl. 1) by use of the ER-55 stereoplotter. A generalized version of this map was incorporated in the new geologic map of Yellowstone National Park (U.S. Geol. Survey, 1972a). Stratigraphic

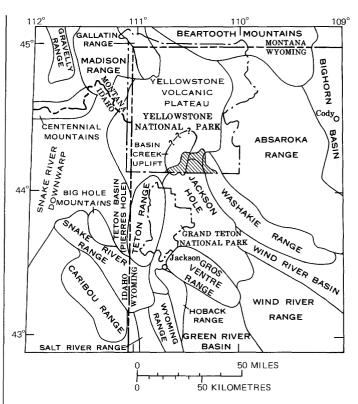


FIGURE 1.—Area of geologic map (slanted lines) and its relation to adjacent uplifts and downwarps.

sections were measured using Brunton compass and 100foot tape, plane table and alidade, and, in part, computations made directly from the topographic base map.

Although many geological observations were made by members of the Hayden surveys and other groups in the 1870's, the first geologic mapping of the sedimentary rocks in this region was that done by Arnold Hague and his colleagues of the U.S. Geological Survey (Hague and others, 1896; Hague, 1904; Hague and others, 1899) as part of their pioneer study of Yellowstone National Park during the late 1800's. Boyd (1961) mapped the rhyolite areas in the park but did not attempt to map the areas of sedimentary rocks. The 1945–49 mapping by Love, Weitz, and Hose was incorporated in the geologic map of Wyoming (Love and others, 1955). Some of the stratigraphic data have been published (Love, 1956a, b, c, d), but none of the measured sections or fossil lists were included in the publications.

GEOGRAPHY

The area of study lies along the headwaters of the Snake River, east and northeast of the South Entrance to Yellowstone National Park (fig. 2). Upstream from the South Entrance the river follows a very sinuous course through broad to narrow valleys and steep gorges (fig. 3); the distance traversed by the stream from the mouth of Fox Creek, in the southeast corner of the mapped area, is about 26 miles. Pack trails are maintained along the entire course

of the Snake River, as well as along many of the tributary streams, and they furnish the main avenues of travel through the area.

Long, narrow, north- and northwest-trending ridges, such as Huckleberry, Big Game (fig. 4), and Chicken (fig. 5) Ridges, dominate the topography of the region. Average elevations along the crests of the ridges are 8,500–9,000 feet above sea level, whereas those of the intervening valleys are generally less than 7,500 feet. Highest peaks in the area include Mount Hancock (elev 10,214 ft) and Barlow Peak (elev 9,622 ft; fig. 5); Mount Sheridan, near the northwest corner of the mapped area, is at an elevation of 10,308 feet (fig. 4).

Some of the steep slopes and upland surfaces in the area, especially those underlain by rhyolitic rocks (frontispiece) are covered by dense growths of evergreens interspersed with small open grasslands; broad outcrops of the Jurassic rocks and the Harebell Formation support only patchy growths of evergreens (figs. 4, 5, 10). Most of

the valley floors have relatively few trees, but the shallow water table results in luxuriant, commonly swampy meadows. The area abounds in a great variety of plant species and wildlife, especially grazing animals, such as deer, elk, and moose.

Average annual precipitation, as measured at the South Entrance ranger station for the period 1905–55, was approximately 30 inches, and average annual temperature was 35°F (U.S. Weather Bureau records). An isohyetal map of the entire area, however, shows 42–46 inches of average precipitation (Mundorff and others, 1964, pl. 2). Measurements of the discharge of the Snake River at the south boundary of the park were made only for 7 complete water years during the period 1913–21; the runoff during the recorded period averaged 858 cubic feet of water per second.

STRATIGRAPHY

Sedimentary rocks (fig. 6) exposed in southern Yellowstone National Park range in age from Devonian to Plio-

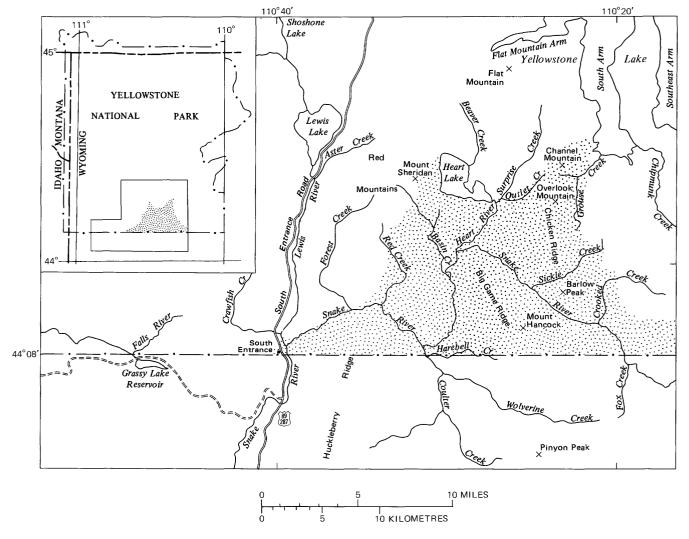


FIGURE 2.—Map showing localities discussed in text. Stippled area is that included in the geologic map.

cene or Pleistocene, except for those in one small locality of Cambrian and Ordovician rocks (pl. 1) along Falls River (fig. 1), west of the area of the geologic map. A thick series of Cretaceous rocks occupies the central part of the area, whereas pre-Cretaceous strata are confined to relatively narrow strips along both the east and the west sides (frontispiece; pl. 1). Small patches of Tertiary and Quaternary volcanic rocks occur in several places, and most of the valley floors and nearby slopes are mantled in part by Quaternary surficial deposits.

Most exposures of the sedimentary rocks are poor, owing to the thick cover of vegetation, glacial debris, and extensive landslides along valley slopes. Slides are especially abundant on steep slopes that are underlain by soft sandstone and shale of Triassic, Jurassic, and Cretaceous ages (frontispiece). The normal vertical continuity of stratigraphic sequences is also disrupted by a complex network of faults in several parts of the area. Consequently, few formations can be seen in their entirety at any single locality.

The classification of rock-stratigraphic units described in this report (fig. 6) is based on nomenclature that is widely used for comparable sedimentary sequences to the south in Jackson Hole and adjoining mountain ranges. Regional data regarding the definition, correlation, lithology, paleontology, and sedimentary history of the various formations are incorporated in many published papers (for example: Love, Duncan, and others, 1948; Love, Keefer, and others, 1951; Love, Hose, and others, 1951; Wyoming Geological Association, 1956; Keefer, 1957; Keefer and Van Lieu, 1966; Love, 1973) and will not be discussed in detail here. Equivalent strata are also present 50 miles away in the northern part of Yellowstone National Park (Ruppel, 1972; Fraser and others, 1969), but in that area a different terminology is used for many of the units, as is shown in figure 6.

Because of cartographic limitations, some formations that were mapped separately in the field have been combined into single stratigraphic units on plate 1.

ROCKS NOT EXPOSED PRECAMBRIAN SYSTEM

No Precambrian rocks are exposed in the area, but their nearby presence is amply indicated by the abundance of locally derived boulders, some 5–10 feet in diameter, in the southeastern part of the area. Apparently, the core of the Washakie Range (figs. 1, 3; pl. 1) was eroded to the Precambrian in Eocene time, and a flood of igneous and metamorphic rock debris was carried southwestward to a locality 1–3 miles northwest of the Fox Creek patrol cabin and incorporated in Eocene pyroclastic strata. The source of the Precambrian debris was probably an area now completely covered by Cenozoic volcanic rocks and glacial debris, lying south of the westward-flowing headwaters of

Crooked Creek, east of the Paleozoic rocks along the Buffalo Fork thrust fault (pl. 1), and north of the Paleozoic rocks along Plateau Creek.

A brief description of the Precambrian rocks is included because nowhere else in or near the southeastern part of the park is there any clue as to the nature of these rocks. Some knowledge of them is helpful in determining the source of Precambrian debris in conglomerates of Late Cretaceous and Paleocene age (Harebell Formation and Pinyon Conglomerate) in this area and also in postulating the influence of Precambrian rocks on the composition of Cenozoic volcanic rocks that came up through them, as well as on Cenozoic folds and faults. The dominant rock type is a pink coarsely crystalline biotite granite containing abundant pink feldspar. A lesser amount of gray, more finely crystalline granite, white quartz pegmatite, black mafic rocks, black and white layered gneiss, green mica schist, and green and black phyllite are present. The schist and phyllite are common, soft, and in angular chunks as much as 3 feet in diameter. These could not have survived transport for more than 2-3 miles. Significantly (as discussed later), the locally derived Precambrian rock debris does not include any quartzite of the type present as boulders in the nearby Harebell Formation and Pinyon Conglomerate. It is assumed, therefore, that the Precambrian terrane exposed during Eocene time did not contain a quartzite facies.

CAMBRIAN SYSTEM

No Cambrian rocks are exposed in the area, but, in the same locality as that containing the Precambrian debris described above, there are boulders, as much as 5-10 feet in diameter, of pink hard quartzitic Flathead Sandstone, blue-gray and tan mottled hard massive Death Canyon Limestone Member of the Gros Ventre Formation, and gray slabby Gallatin Limestone. The Gallatin contains characteristic "edgewise conglomerate." These rocks have the same general appearance and lithology as those described in the Teton Range, 30 miles to the southwest (Love and Reed, 1968). The source of the Cambrian boulders doubtless was outcrops flanking the now-buried Precambrian core of the Washakie Range 2-4 miles north and northeast of the Fox Creek patrol cabin. Regional studies show that the Cambrian rocks there are about 1,000 feet thick.

ORDOVICIAN SYSTEM, BIGHORN DOLOMITE

No bedrock outcrops of Ordovician strata are now exposed in the area, but ragged-weathering angular boulders of chalky white to gray siliceous Bighorn Dolomite are present in the same locality as the Cambrian and Precambrian boulders. Doubtless, the area of Bighorn outcrop was more extensive than that of the Cambrian and Precambrian along the crest of the Washakie Range, for boulders as much as 17 by 10 by 6 feet were observed on



Figure 3.—Relief map showing general outline of area described in this report and geographic features in the Yellowstone National Park– Jackson Hole region.

Pinyon Peak, 7 miles southwest of the Fox Creek patrol cabin. Regional studies show that the Bighorn is virtually all dolomite and is about 400 feet thick in this area.

EXPOSED ROCKS DEVONIAN SYSTEM, DARBY FORMATION

The only exposure of the Darby Formation is a small outcrop about 1 mile northwest of the Fox Creek patrol cabin, in the southeast corner of the mapped area. The rocks consist of 50 feet of yellow and red shale, thin-bedded and platy dolomite, and granular fetid brown dolomite, which represent the upper part of the formation.

The dolomite occurs at the base of a vertical to overturned sequence of Paleozoic strata along the toe of the overriding (east) block of the Buffalo Fork thrust fault (pl. 1). The top of the unit appears to be in normal contact with typical gray massive limestone of the Mississippian Madison Limestone, but the base is obscured by pyroclastic rocks of Tertiary age. The total thickness of the Darby is probably about 250 feet in this area. Mashing and distortion associated with faulting, however, have given the outcrop a much greater width than would be expected for a unit with this thickness.

The assignment of the dolomite to the Darby Forma-

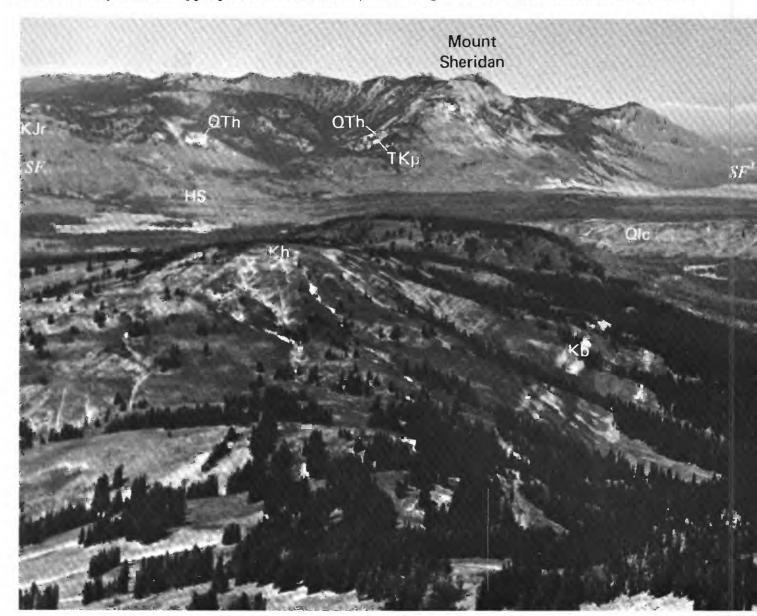
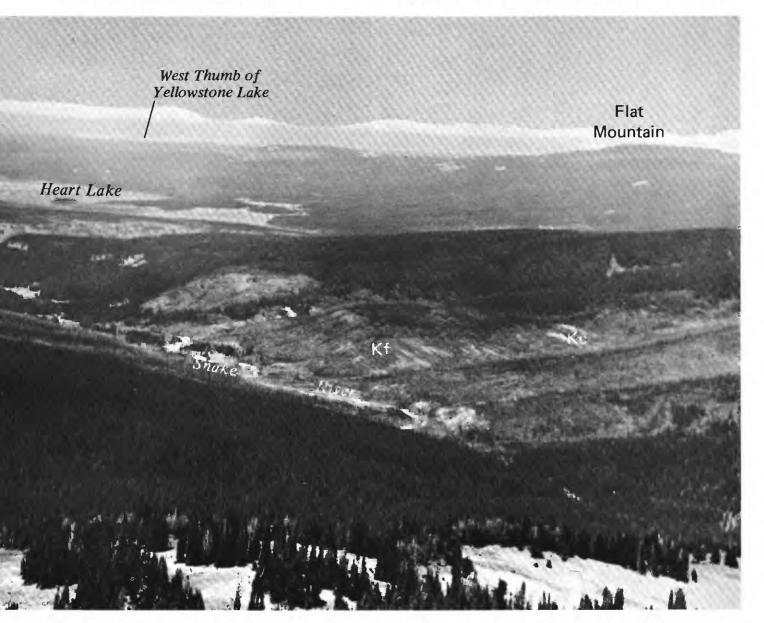


FIGURE 4.—View northwest from Mount Hancock toward Mount Sheridan, showing Cretaceous strata on both flanks of the Wolverine antiof upfaulted Pleistocene Huckleberry Ridge Tuff, and Flat Mountain is composed of rhyolite welded tuff. Shown are: Pleistocene Lava Ridge Sandstone (Kb) and Harebell Formation (Kh) on the west flank (Big Game Ridge in left foreground); Basin Creek hot spring Conglomerate (TKp) where it rests on Lower Cretaceous rocks; and Sheridan normal fault (between SF and SF') along the break

tion is based on stratigraphic position below the Madison Limestone and on lithologic similarities with sections of the formation that have been observed by the authors at many localities in the Washakie and Gros Ventre Ranges to the south, and the Teton Range 30 miles southwest (Love and Reed, 1968; Love and Keefer, 1969b; Benson, 1966). It also is similar to the Logan Gulch Member of the Three Forks Formation, as that unit is defined in northern Wyoming and southern Montana by Sandberg (1965, p. N11) and Benson (1966). The age of the Logan Gulch Member is considered to be Late Devonian. No fossils were found in the Darby in the mapped area.

MISSISSIPPIAN SYSTEM, MADISON LIMESTONE

The Madison Limestone crops out in several places along both the east and the west sides of the mapped area (pl. 1). The best exposures are on the sides of a deeply incised ravine that descends the north slope of Huckleberry Ridge and crosses the South Boundary trail about 3 miles northeast of the South Entrance. The basal part of the formation is covered by surficial deposits of the Snake River valley at this locality, but southward along the ravine approximately 1,100 feet of strata is exposed in steep canyon walls. A comparable thickness is present in a complete but somewhat deformed section of the Madison



cline and their relation to the faulted Basin Creek uplift and overlapping Pleistocene rhyolite welded tuffs. Mount Sheridan is composed Creek Tuff (Qlc); sandstones in Frontier Formation (Kf) and Cody Shale (Kc) on the east flank of the Wolverine anticline and Bacon area (HS); Cretaceous and Jurassic rocks (KJr) on the southeast flank of the Basin Creek uplift; Heart Lake Conglomerate (QTh); Pinyon in slope. Photograph by J. D. Love, Sept. 2, 1948.

15 miles to the east, near the southeast corner of the area (pl. 1).

The Madison consists chiefly of white to gray and bluish-gray massive to thin-bedded crystalline limestone. It characteristically has a fetid petroliferous and sulfurous odor on fresh fractures. Solution cavities are common. A few zones are dolomitic. In some dolomites northwest of Red Creek are several zones of black chert in layers as much as 2 inches thick. A thin (5–10 ft) unit of black and red shale was observed near the middle of the formation at one locality in the southwestern part of the area. A characteristic feature of the formation is the abundance of fossils, especially horn and colonial corals and brachiopods, at many horizons; regionally, the varied invertebrate marine fauna of the Madison indicates a Mississippian age (Sando and Dutro, 1960, p. 122; Sando, 1967, fig. 7).

The Madison Limestone is overlain by sandstone of the Amsden Formation, commonly along a sharp irregular contact. A thin layer of red earthy material occurs locally; it probably accumulated on a karst surface as a result of weathering and solution of the underlying limestone. These contact phenomena between the two formations are present throughout much of northwestern Wyoming.

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS, AMSDEN FORMATION

The Amsden Formation is characterized regionally by | half mile west of the mouth of Red Creek, where the Dar-

a basal sandstone unit (Darwin Sandstone Member) and an upper variable sequence of shale and carbonate rocks. The formation is very poorly exposed in the mapped area, but scattered outcrops indicate that the twofold division is probably everywhere present. A generalized section, measured on a prominent spur along the north slope of Huckleberry Ridge, approximately 2.5 miles east-northeast of South Entrance, is as follows (measured by W. R. Keefer, 1967):

Tensleep Sandstone (not described).

Amsden Formation:

Thickness (feet)

Upper part:

- 3. Shale, red and purple, finely fissile; sandy in basal 2 ft..... 24

Darwin Sandstone Member:

- Total thickness of Amsden Formation230

 Madison Limestone (not described).

Additional outcrops of the Amsden Formation are present on the north side of the Snake River flood plain, onehalf mile west of the mouth of Red Creek, where the Dar-



FIGURE 5.—View northeast from top of Mount Hancock across the canyon of the Snake River, showing at extreme right margin the lower part of the type section of the Harebell Formation. About 3,000 feet of Harebell is exposed on Chicken Ridge, and 2,700 feet on Barlow Peak. Indicated are Cody Shale (Kc) and the unconformable contact between the Bacon Ridge Sandstone (Kb) and the Harebell Formation (Kh) Photograph by J. D. Love, Sept. 2, 1948.

Age South (This report)		North (Ruppel, 1972, fig 4)		Terminology of Hague and others, (1896, 1899) and Hague (1904)				
QUATER- NARY	Pleistocene	Yello	ows	tone Group and Lewis Canyon Rhyolite 0–1,000 ft			Rhyolite	
700 N	Pleistocene or Pliocene	He	art	Lake Conglomerate 0–330 ft			(Not distinguished)	
>	Miocene	С	olt	er Formation (3 miles south of park) 0-1,000 ft		(Not listed)		
Æ	Oligocene		iver	Formation (3 miles south of park)				
ERTIARY	Eocene	Absaroka Volcanic Super- group		Wiggins Formation 0-1,000 ft			Late basic breccia (part)	
_		Absa Vol Su gre		Langford Formation 0-500 ft			Early basic breccia (part)	
	Paleocene	F	Piny	yon Conglomerate 0-450 ft			Pinyon Conglomerate	
		ŀ	Har	ebell Formation 0-9,000 ft	L	andslide Creek Formation	Laramie Formation	
				(Absent)		Everts Formation	<u> </u>	
1	Late					Eagle Sandstone	Montana Formation	
		Bac	on	Ridge Sandstone 500-1,700 ft	Т	elegraph Creek Formation	1	
SO				Cody Shale 1,750 ft		Cody Shale		
Ü			F	rontier Formation 850 ft		Frontier Sandstone		
AC		Mov	vry	Shale and locally upper black		Mowry Shale	1	
CRETACEOUS	j	rmo- lis ale Oft	Γ	mber, Thermopolis Shale 650 ft Muddy Sandstone Member 100 ft	lis.	Upper sandstone member	Colorado Formation	
	Early		Lower black shale member		Thermopolis Shale	Middle shale member		
	pui (¿)			Rusty beds member 100 ft	T he	Lower sandstone member	*	
JURASSIC		son atic	atic		Kootenai Formation		Dakota Formation	
		Rusty beds member 100 ft Lowerly and to the control of the contro		Morrison Formation		- Dansta v smatts.		
		Sundance Formation		"Upper Sundance" 80 ft	_	Swift Formation		
				"Lower Sundance" 375 ft	Ellis Group	Rierdon Formation	Ellis Formation	
				0 : -		Sawtooth Formation	<u> </u>	
		Gypsum Spring Formation 50 ft Chugwater Formation 1,000 ft			Thaynes(?) Formation			
7	TRIASSIC			Woodside Formation		Teton Formation		
			Dir	nwoody Formation 200 ft	Dinwoody Formation		1	
PERMIAN Phosp		Phosphoria Formation and related rocks 200 ft		Shedhorn Sandstone				
PENI	VSYLVANIAN	Tensleep Sandstone 380 ft			Quadrant Sandstone			
			Amsden Formation 230 ft		Amsden Formation		Quadrant Quartzite	
MIS	SSISSIPPIAN	Madison Limestone 1,100 ft		Madison Group	Mission Canyon Limestone	Madison Limestone		
					Ωā	Lodgepole Limestone		
DEVONIAN		Darby Formation 250 ft			Three Forks Formation	Three Forks Formation		
				Jefferson Formation		Jefferson Formation		
ORDOVICIAN CAMBRIAN		Gallatin Limestone Snead by the second of th		Bighorn Dolomite 400 ft		Bighorn Dolomite		
				Gallatin Limestone	Snowy Range Formation		Gallatin Formation	
				Pilgrim Limestone				
				Park Shale	1			
				Meagher Limestone		1		
		exp.	٦		Wolsey Shale		Flathead Formation	
		ot		Flath and Conditions			-	
		Z		Flathead Sandstone	Flathead Sandstone			

^{*}Quartzite units included in Sheridan Quartzite by Hague and others (1896) near Mount Sheridan and considered by him to be Precambrian in age. The name Sheridan has been abandoned.

FIGURE 6.—Nomenclature and approximate correlations of rock units in Yellowstone National Park.

win Sandstone Member apparently is somewhat thinner than in the section described above. The upper 30 feet of the Darwin is exposed and is overlain by 20 feet or more of red and purple shale and claystone containing gray limestone nodules.

The following section of the upper part of the Amsden Formation and lower part of the Tensleep Sandstone was measured along a low ridge 1,000 feet east of the junction of the Lewis and Snake Rivers (measured by J. D. Love, Sept. 9, 1949):

Tensleep Sandstone (part):

feet)

Amsden Formation (part):

- Sandstone, snowy-white; weathers brown; fine grained; hard, but not quartzitic; appears to be almost entirely quartz grains; poorly and irregularly bedded.....
- 1. Dolomite, light-brown to dull gray, hard, cherty, slightly sandy; in ragged beds; traces of red shale and siltstone in alluvial debris that overlaps base.....21

 $Total thickness of measured part of Amsden Formation \ 59 \\ Base of exposures; overlapped to east by travertine.$

The contact between the Amsden Formation and the overlying Tensleep Sandstone is marked by a change from thin-bedded carbonate rocks below to massive sandstone above. The lithologic change is commonly gradational, however, and, because the contact zone is poorly exposed in most places, the two formations were mapped as a single unit.

Regional stratigraphic and paleontological data indicate that the Darwin Sandstone Member, as well as some of the overlying strata, are Mississippian (Chesterian) in age (Sando, 1967, p. 550). The upper part of the Amsden, however, is of Pennsylvanian age. The following fossils were identified by L. G. Henbest (written commun., May 18, 1970) from chert nodules in unit 3 of the section east of the junction of the Lewis and Snake Rivers:

Komia(?) sp. (alga or hydroid)
Cornuspirinae (tubiform)
Taxtulariidae
Climacammina(?) sp.
Tetrataxis of the T. millsapensis gr.
Endothyra sp.
Millerella sp.
Eostaffella(?) sp. (obscure)
"Fusulinella" sp.

Bryozoan fragments Brachiopod spines Productid spine Echinoderm plates Crinoid columnals

He commented on this assemblage as follows:

I have not yet determined the generic relations of the species of "Fusulinella" here listed for my Amsden-Tensleep report, but it and the associated forams agree in indicating a biostratigraphic horizon in Wyoming and adjacent areas that seems rather definitely to be of early Atokan age. I have not seen any example of this species of "Fusulinella" in rocks that were known to be of Morrowan age nor in rocks now regarded as of Des Moinesian age. Though Atokan age seems to be definitely indicated, I do not think that the age of this faunal zone is finally settled.

PENNSYLVANIAN SYSTEM, TENSLEEP SANDSTONE

The Tensleep Sandstone is a white, gray and buff very fine to medium grained, in part quartzitic, sandstone. Individual units are generally massive and in part crossbedded. Thin beds of carbonate rocks occur in places. Unlike the conspicuous cliff-forming outcrop character of the Tensleep in adjoining regions, the formation within the mapped area, except along the Snake River (frontispiece), is tree covered and forms rather subdued bluffs and ledges. No detailed section of the formation was obtained, but a thickness of 380 feet was measured along the north slope of Huckleberry Ridge.

On the west fork of Red Creek the upper 100 feet of Tensleep is exposed in sheer canyon walls north of Val Dome (frontispiece). The sandstone has been altered to quartzite with a glassy sheen. About 30 feet below the top is a 5-foot red claystone with green mottling. This unit looks like the red beds in the Amsden but is so high in the Tensleep section that it must represent a local uncharacteristic facies.

The contact between the Tensleep Sandstone and overlying Permian rocks either is covered or is involved in structural complications at most localities. Where exposed, however, the basal beds of the Permian sequence are conglomeratic and phosphatic and contain more chert than the underlying Tensleep.

No fossils were found in the Tensleep Sandstone of this area, but, in localities to the south and southeast in Jackson Hole, the Tensleep is Pennsylvanian (Des Moinesian and younger) in age (Love, 1954).

PERMIAN SYSTEM, PHOSPHORIA FORMATION AND RELATED ROCKS

Permian rocks in southern Yellowstone National Park contain equivalents of the Phosphoria Formation and Shedhorn Sandstone (Sheldon, 1963, p. 160–162); they are therefore designated as "Phosphoria Formation and related rocks" for purposes of this report. No complete sections of the sequence have been measured in the mapped area; almost everywhere the topmost beds are covered, are intruded by igneous dikes, or are cut by faults. Sheldon (1963) measured 148 feet of strata near the mouth of Red

Creek and postulated that 15 feet more had been faulted out (1963, fig. 12), giving a total thickness of 163(?) feet. Observations of outcrops 2,500 feet south-southeast of the mouth of Red Creek, where the upper part of the sequence is present, and average measurements computed at several adjacent localities indicate that the thickness of the Phosphoria Formation and related rocks is probably nearly 200

The section on Red Creek, measured by Sheldon (1963, p. 160-162), is generalized as follows:

Probable fault contact; relationships are obscured by poor exposures, but the uppermost beds of the Phosphoria Formation and related rocks, as well as the overlying Dinwoody Formation, are apparently

Chugwater Formation (not described).

Tensleep Sandstone (not described here).

faulted out. Phosphoria Formation and related rocks (part): 10. Sandstone, dark-gray, fine-grained, hard, slightly phosphatic, fossiliferous 8 9. Chert, light- to dark-gray; thick-bedded in part; hard, brittle; sandy in part, with very fine sand grains........... 46 8. Phosphorite, black, cherty, fossiliferous...... 1 7. Sandstone, light-brownish-gray, fine-grained, massive, hard..... 6. Chert, light-brownish-gray, massive, hard, sandy...... 5. Sandstone, gray, yellowish-gray, and brown, fine- to coarse-grained, thick-bedded to massive, hard, phosphatic; contains abundant tubular concretionary masses of chert and cherty sandstone...... 37 4. Dolomite, gray and brown, thick- to thin-bedded, sandy, fossiliferous..... 3. Sandstone, gray, fine- to medium-grained, massive, hard, fossiliferous; some thin beds and irregular masses of 2. Dolomite, light-gray, thick-bedded to massive, hard, sandy, 1. Sandstone, gray to light-brown, fine-grained to very coarse grained, massive; conglomeratic in part with chert pebbles as much as 20 mm in diameter; basal contact sharp and irregular...... 8 Total measured part of Phosphoria Formation and related rocks148

The basal beds of the Phosphoria sequence are well exposed in several places along Red Creek. At the upper falls on this creek, the uppermost beds of the Tensleep are light-gray very hard coarsely bedded brittle finegrained quartzite forming fractured cliffs. The contact line between the Tensleep and Phosphoria is completely exposed for 50 feet. Maximum relief along the contact is 3 feet vertically in a horizontal distance of 6 feet. The lower 2 feet of unit 1 in Sheldon's section, given above, contains abundant pebbles of chert, milky white crystalline quartz, and quartzite, as much as 2 inches in diameter but averaging about one-fourth inch, embedded in a fineto medium-grained gray quartzite matrix. Higher in unit 1 the pebbles become much less abundant. About 20 feet above the base of the formation here there is a 2-foot zone containing numerous asphalt-filled vugs.

Another locality where the cherty basal part of the Phosphoria is well exposed is at the northeast high point of the structural dome on Red Creek (Val Dome, shown in frontispiece), 5,000 feet southwest of Basin Creek Lake. The following section was measured by J. D. Love, Aug-

The following section was measured by J. D. Bove, The	^5
ust 28, 1949: Thick	
Phosphoria Formation and related rocks (part): (fee	t)
5. Chert and quartzite, dark-gray, nodular; forming wall and	
big dip slope on northeast side of dome	20
4. Phosphorite, black, sparsely fossiliferous; gradational con-	
tacts at base and top	2
3. Chert and quartzite, dark-gray, massive, nodular	20
2. Sandstone, dark-gray, conglomeratic; contains pebbles,	0
phosphate pellets, fish teeth, and brachiopods	2
grained; contains irregular chert nodules	15
_	15
Total measured part of Phosphoria Formation and related rocks	50
Tensleep Sandstone (not measured).))
The following section of the middle part of the Pho	
phoria was measured on cliffs along a steep north-flo	w-
ing ravine 13,500 feet east of the South Entrance of Ye	el-
lowstone National Park and 1,700 feet north of the sou	
boundary of the park (measured with steel tape by J.	
Love, J. L. Weitz, and R. K. Hose, August 1949):	
•	
Thickn	
Dike of highly altered felsic igneous rock that separa	
upper part of Phosphoria from lower part of Di	
woody Formation.	111
Phosphoria Formation and related rocks (part):	
10. Sandstone, gray-green, slightly phosphatic, slightly	
dolomitic, hard, massive in lower part, coarsely bedded	
in upper part; forms massive ledge below white talus	
of volcanic rock; top 6 in. is soft and ferruginous, with	
thin green opal(?) stringers	27
9. Chert, light-greenish-gray, hard, brittle; appears chalky	
and weathered at top	l
8. Sandstone, light-gray-green, dolomitic; interbedded with	
sandy irregularly bedded chert; lower 6 in. is phosphatic	2
7. Dolomite, light-gray-green, crystalline, slightly glauconi-	
tic; numerous phosphatic nodules and irregular hard	
chert masses; many poorly preserved fossil fragments	4
6. Chert, light-gray-green, bedded, brittle	1
5. Sandstone, dark-gray, highly phosphatic; numerous in-	
testine-shaped masses of gray-green chert; top 3 in. is	
fossiliferous phosphorite; unit forms ragged nodular	4
ledge4. Sandstone, dark-gray, highly glauconitic; contains large	1
turquoise-green grains; slightly dolomitic, very hard,	
almost quartzitic; massive to irregularly bedded at top;	
upper 1 ft is phosphatic and contains fish teeth and	
phosphatic brachiopods	10
3. Chert, black to dark-gray; in intestine-shaped masses sep-	
arated by dark gray silty matrix; very hard and forms	
ragged conspicuous ledges; upper 4 ft is quartzitic and	
contains some phosphate granulesl	12
2. Sandstone, dark-gray, highly silicified, quartzitic, slightly	
who are books arouse board are conting	c

phosphatic, very hard, massive.....

arated by dark-gray silty matrix; very hard and forms

ragged conspicuous ledges23

1. Chert, black to dark-gray; in intestine-shaped masses sep-

One of the few exposures of the upper part of the Phosphoria and its contact with the overlying Dinwoody Formation is 2,500 feet south-southeast of the mouth of Red Creek, at a sharp bend along the north bank of the Snake River, on the uppermost of several fault blocks. Although small-scale faulting complicates the relation of the units, the following stratigraphic succession has been reconstructed (measured by J. D. Love, 1945, 1949):

Dinwoody Formation (part):	Thickness (feet)
4. Shale and quartzitic siltstone, dark-gray, interbedde hard	
Phosphoria Formation and related rocks (part): 3. Shale, dark-gray to black, siliceous, flinty, brittle, ver 2. Quartzite, dark-gray, brittle, phosphatic; forms ledg 1. Chert, black, hard, brittle, phosphatic; upper sur conspicuously irregular	re 4
Total measured part of Phosphoria Formation	

None of the above sequence could be correlated with assurance with the uppermost beds in Sheldon's Red Creek section, cited earlier, so is thought to overlie them and to have been faulted out in that section.

The base of the Phosphoria is marked by an erosional unconformity with some local relief; this unconformity represents a major time break. Farther south in Jackson Hole, at the position of this break, is several hundred feet of Middle and Upper Pennsylvanian rocks (Love, 1954) that have been eroded from the southern Yellowstone area. The contact with the overlying Dinwoody Formation of Triassic age appears conformable.

Abundant fossils indicate an Early and Late Permian age for the Phosphoria Formation and related rocks in northwestern Wyoming (Yochelson, 1968, p. 622–627; McKee and others, 1967, table 1).

TRIASSIC SYSTEM DINWOODY FORMATION

The Dinwoody Formation, present in the eastern and western parts of the mapped area, is characterized by greenish-gray to brown slabby hard dolomitic sandstone and siltstone and green shale. Outcrops are a distinctive brown that, in places, appears almost black. No complete section was measured but the thickness is estimated to be about 200 feet. The best exposed section is 13,500 feet east of the South Entrance of Yellowstone National Park and 1,200–1,500 feet north of the south boundary of the park, in the same steep north-flowing ravine where a partial section of the Phosphoria Formation and related rocks, previously cited, was measured. (Measured with steel tape by J. D. Love, J. L. Weitz, and R. K. Hose, August 1949):

Thickness (feet)

Chugwater	Formation	(part	١:

11. Partly covered interval; siltstone, red, slabby, in float....... <u>50+</u>
Approximate contact between Chugwater and Dinwoody Formations arbitrarily placed at attractory bigs.llv. bigbest accountered

tions arbitrarily placed at stratigraphically highest occurrence of float of Dinwoody lithology.

10. Partly covered interval; some blocks of olive-drab Din-

Dinwoody Formation (part):

- 4. Shale and claystone, greenish-gray, blocky to fissile.......83. Siltstone and shale, interbedded, light-greenish-gray;

Total measured part of Dinwoody Formation...........170± Dike of highly altered felsic igneous rock that separates lower part of Dinwoody Formation from upper part of Phosphoria Formation and related rocks.

In the eastern part of the mapped area, steeply dipping slabby tawny dolomitic siltstone beds on the west flank of the Washakie Range, 9,000 feet north-northwest of milepost 29 on the southern boundary of Yellowstone National Park, contain masses of well-preserved pelecypods.

Because the Dinwoody Formation is moderately thin and very poorly exposed in most places, it was combined with the overlying Chugwater Formation on the geologic map. The Dinwoody is considered to be of Early Triassic age (Newell and Kummel, 1942, p. 942–943; McKee, Oriel, and others, 1959), and apparently is bounded by conformable contacts, both at its base and at its top.

CHUGWATER FORMATION

The Chugwater Formation—because it is bright red and nearly 1,000 feet thick—is one of the most conspicuous sedimentary rock units in the area. It forms broad outcrop belts along the crest and north slope of Huckleberry Ridge and in the valleys of Red, Basin, and Crooked Creeks. The sequence, predominantly interbedded siltstone, sandstone, and shale, can be separated from top to bottom into the Popo Agie, Crow Mountain Sandstone, Alcova Limestone, and Red Peak Members. These subdivisions are based on regional correlations established by Love, Johnson, Nace, and others (1945) and by Love, Keefer, Duncan,

and others (1951) in central and northwestern Wyoming. | Chugwater Formation-Continued Recently, it was proposed (High and Picard, 1967, p. 77; Pipiringos, 1968, p. D2) that the Chugwater be raised to group status and that the various members be raised to formational status in parts of central and south-central Wyoming. In southern Yellowstone National Park, however, on the map scale of 1:62,500 used for this report (pl. 1), it was not feasible to map the Alcova (10 ft thick), Crow Mountain (40–70 ft thick), and Popo Agie (70–100 ft thick) as separate formations. Therefore, the Chugwater was mapped as a single formation for purposes of this investigation, and the various subdivisions are treated as members.

The tollowing section was measured from the north slope of Huckleberry Ridge southward across the park boundary, 1,500 feet west of milepost 14 (measured with plane-table control for major units and with steel tape for detail by J. D. Love, J. L. Weitz, and R. K. Hose, Aug-Thickness

ust 1949): Gypsum Spring Formation (part): 35. Gypsum and limestone breccia, light-gray, spongy; composed chiefly of calcium carbonate and some gypsum; believed to be a residual breccia left after surface and near-surface leaching out of gypsum...... 13 34. Shale, dark-red, silty, blocky......2 Contact between Gypsum Spring Formation and Popo Agie Member of Chugwater Formation arbitrarily placed at top of this covered interval; however, on the basis of the Snake River section presented next, it may be about 10 ft below the breccia. Chugwater Formation: Popo Agie Member: 31. Claystone, light-reddish-gray, silty, soft; 5 ft above base, color grades up to brown and red with some ocher blotches; top 6 in, is light greenish gray...... 12 30. Conglomerate, purple; containing subrounded limestone pellets 1-10 mm in diameter 29. Silt shale, purple to gray; has some green layers; limy; interbedded with 4 lenses of light-greenish-gray limy fine-grained hard sandstone 3-9 in. thick; thin limestone pellet conglomerate above sandstone ledge 2 ft above base 28. Sandstone, light-grayish-red, very fine grained; grades up to a 3-in. limestone pellet conglomerate made up of a green matrix and gray rounded pellets that have an average size of one-fourth inch; several red bone fragments and one biconcave vertebra 2 27. Covered interval 26. Sandstone, greenish-gray, limy, very fine grained, very hard, almost quartzitic; forms ledge..... 24. Sandstone, greenish-gray to red, limy, very fine grained ... 1 23. Silt shale, dark-red; has green silt laminae; limy...... 1 22. Sandstone, grayish-red, green in part, limy, very fine grained; very hard and ledgy in upper part as well as basal 8 in. 21. Siltstone, purplish-red, limy, soft..... 20. Sandstone, light-greenish-gray, very fine grained, massive; forms conspicuous ledge 2

Chagward Tornadon—Conditacd	kness et)
Popo Agie Member—Continued	<i>e.</i> ,
17. Silt shale, grayish-red, limy; interbedded with light- greenish-gray limy very fine grained sandstone in 6-	
in. to 4-ft beds	8_
Total thickness of Popo Agie Member	95
Approximate contact between Popo Agie and Crow Mountain Sastone Members. This contact is probably gradational and is plant this position partly on the basis of data from sections to north and northeast.	aced
Crow Mountain Sandstone Member: 16. Sandstone, light-grayish-green, limy, very fine grained, moderately hard, massive; interbedded with red thin-bedded siltstone in ratio of 10:1; 1 ft of pale-red very fine grained sandstone 9 ft above base	1 2 4 21
 Siltstone; light greenish gray with dark-brown blebs; very limy, soft, thin bedded	2 1 7
Total thickness of Crow Mountain Sandstone Member	71
Alcova Limestone Member: 6. Limestone, very light gray to light tan, clayey, thin-bedded; beds 1/2 in. thick; numerous red shale laminae that appear as red streaks on bedding planes	10
Red Peak Member: 5. Siltstone, brick-red, finely sandy; grades into very fine grained silty sandstone, containing sparse thin red shale partings; moderately soft; has a few ledge-forming beds; limy in upper half; fissile in part; thin bedded to poorly bedded; harder beds weather to large angular blocks; some thin light-green siltstone beds in upper 15 ft; bedding planes purple in upper part	329 23 119
Total thickness of Red Peak Member	970 ions

A well-exposed unfaulted section of the upper part of the Chugwater Formation with strike N. 10° W., dip 18° NE., along a high cliff on the northeast side of the Snake River, 4,000 feet southeast of the mouth of Red Creek (pl. 1), was measured with steel tape by J. D. Love, July 31, 1972:

Thi	ckness
	eet)
20. Dolomite breccia, gray, hard, porous, composed of chaoti-	-
cally jumbled blocks	10+
19. Siltstone, dark-red, hard, blocky, with some gray dolomite	
partings	
18. Sandstone, salmon-red, very soft; has large frosted rounded	
quartz grains; appears identical to Nugget Sandstone	
and is in the proper stratigraphic position, but the	
northern wedge edge of the Nugget, as far as is	
known, is about 33 miles to the south; contacts at both	
top and base sharp	2
Total measured part of Gypsum Spring Formation	
Chugwater Formation (part):	
Popo Agie Member:	
17. Claystone, dolomitic siltstone, and silty dolomite; dolo-	
mite is light greenish gray and in massive hard ledges;	
siltstone is hackly, sandy, dolomitic, poorly bedded	
16. Siltstone and sandstone, purple, limy; contain several	
lenticular lime-pellet conglomerates; ledge of gray hard	
dense limestone 2 ft thick at top	
15. Claystone and siltstone, red and green polka dotted; forms	
reentrant in cliff	
14. Siltstone, purplish-red and green, hard, brittle; forms part	
of cliff	
13. Limestone pellet conglomerate, gray to lavender, with	
amber-colored plates or teeth(?)	
12. Siltstone, brick-red, hard, cliff-forming, fine-grained,	
poorly bedded; breaks with hackly surface	
Total thickness of Popo Agie Member	36.3
Crow Mountain Sandstone Member:	
11. Sandstone and sandy silty dolomite, red and green, fine-	
grained, thick-bedded, cliff-forming; basal 3 ft is gray	
hard massive limy dolomite or dolomitic limestone	
overlain by 1 ft of red shale; remainder of sandstone	
is green and so limy or dolomitic that it is almost as	
much a carbonate rock as sandstone	12
10. Sandstone, silty, siltstone, and shale, all red, interbedded,	
in about 3-ft beds	
9. Sandstone, brick-red, massive to poorly bedded, hard,	
brittle; forms cliff	
8. Shale, brick-red, silty, soft	l
7. Sandstone, pink, quartzitic, brittle, massive; forms clift	8
6. Sandstone, red, hard; has 1-ft-thick red shale bed at top	5
5. Siltstone, red, hackly; forms pitted unit on cliff face	3
4. Sandstone, red, forms basal part of big cliff (frontispiece);	
contains frosted rounded quartz grains in finer matrix	
6 ft above base; has thick even bedding; is hard and	
homogeneous; merges upward with overlying unit	26
3. Siltstone, red, slabby, soft; forms slope up to base of big	
cliff (frontispiece)	25_
Total thickness of Crow Mountain Sandstone Mem-	
ber	
Alcova Limestone Member:	
2. Dolomite, white to lavender, hard; has thin even bedding;	
marly at base and top; forms low ledge	

Thickness(feet)

Chugwater Formation (part)—Continued

Red Peak Member:

1. Siltstone, silty sandstone, and shale, brick red, in thin even layers; hard, but forms steep slope (frontispiece) 400+ Total measured part of Chugwater Formation......578.5+

Additional details of the Triassic strata were obtained from outcrops on a north-facing slope that culminates in a high ridge 2,000 feet northwest of VABM Snake triangulation station, elevation 9,213 feet, 5,000 feet north of the southern boundary of Yellowstone National Park (measured by J. D. Love, Sept. 7, 1945):

(, J,,,,,,
Thickness Gypsum Spring Formation (part): (feet) 6. Gypsum, snowy-white, finely crystalline, soft 15+ 5. Siltstone, dark-red, soft (fig. 7) 10
Chugwater Formation (part): Popo Agie and Crow Mountain Sandstone Members: 4. Claystone and siltstone, red and purple, mottled with green; contains several lenses of purple limestone-pellet conglomerate; several beds of gray quartzitic sandstone near base; lower part so poorly exposed that contact between members was not picked
3. Sandstone, salmon-pink to brick-red, fine- to medium-grained; has some large rounded frosted grains
Alcova Limestone Member: 2. Dolomite, white to purple, with pink laminae; dense, very hard; has conchoidal fracture; upper and lower contacts appear gradational through thin zones of silty dolomite and dolomitic siltstone
Red Peak Member: 1. Siltstone, brick-red; interbedded with brick-red fine-grained silty sandstone, hard, ripple marked

Approximately 6 miles northeast of the above section, the same part of the Triassic sequence was measured on an outcrop 3,200 feet due north of the east margin of Basin Creek Lake, on the north edge of a steep ravine draining the precipitous east face of a major hill (measured by J. D. Love, Aug. 24, 1949):

	Thickness
Gypsum Spring Formation (part):	(feet)
21. Limestone breccia, tan to gray, irregularly bedded; p	rob-
ably a solution breccia from which gypsum was	dis-
solved	10±
20. Siltstone and claystone, dark-brick-red, soft, finely blo	cky,
micaceous	
Contact between Cynsum Spring Formation and Pono Agie	Member

Contact between Gypsum Spring Formation and Popo Agie Member of Chugwater Formation.

Chugwater Formation (part):

Popo Agie Member:

19. Siltstone and fine-grained sandstone, red and gray, blotched, irregularly bedded, moderately soft...... 1 18. Siltstone, purple; blotched with greenish-gray; blocky, poorly bedded 1

Thickness Chugwater Formation (part)—Continued Popo Agie Member-Continued 17. Siltstone; brick red with orange tinge; hard, massive; breaks into angular talus blocks; homogeneous; has some fine sand grains; basal 1.5 ft is dolomitic and gray, grading up through a blotchy zone to red............ 15 15. Dolomite and dolomitic siltstone, gray; red blotches in lower part; massive, hard; forms ledge 1 14. Siltstone, brick-red, massive, coarsely blocky; blotched with green in upper part...... 5 13. Dolomite, light-gray, earthy, hard, silty; red blotches in upper half; forms ragged ledges...... 3 12. Shale and claystone, purple to red, soft; blocky in lower part; harder, red, and poorly bedded at top...... 4 11. Siltstone; purplish red in upper half, gray in lower half; has 6-in. red parting 1 ft above base; dolomitic, poorly 10. Dolomite, light-gray, silty, very hard; purple laminae in lower half and looks superficially like Alcova Limestone; Member upper half massive; forms ledge 2 9. Shale, purple, silty, hard 8. Siltstone; yellowish-gray in lower part; blotchy red and yellow near top; very dolomitic in lower half; hard; 6. Dolomite, greenish-gray, very silty, hard; forms ledge 1 5. Limestone-pellet conglomerate 3 in. thick at base, green to red, typical of Popo Agie in adjacent areas; remainder is blotchy red and green siltstone; dolomitic; has thin gray beds of silty dolomite or dolomitic silt-Total thickness of Popo Agie Member67 Crow Mountain Sandstone Member: 4. Variable sequence; red blocky siltstone mottled with green; interbedded with gray coarse-grained lenticular sandstone beds that weather yellow like Cretaceous sandstones in this area; sandstone has coarse and angular to frosted and rounded large grains in finer matrix; red siltstone in middle; 8 ft below top is 1 ft of gray dolomitic siltstone that superficially looks like Alcova Limestone Member and that is interbedded with yellowish earthy dolomitic siltstone blotched with red; the coarsegrained sandstone is very striking and distinctive and Total thickness of Crow Mountain Sandstone Member......<u>40</u> Alcova Limestone Member: 2. Dolomite, creamy-white; so fine grained that it appears to be lithographic; laminated; some pink laminae; very hard, slabby; some contorted bedding; some vugs 2 Red Peak Member: 1. Siltstone, brick-red, hard and finely sandy in lower 80 ft, forming ragged blocky cliffs with talus slopes; upper 40 ft is softer, more shaly, and more poorly exposed than underlying part......120 Total measured part of Chugwater Formation......229 Underlying strata not exposed.

The thinning of the Popo Agie, as documented by the above sections, is caused at least in part by an unconformity of regional extent at its top. From south to north progressively older beds were eroded away prior to deposition of the Middle Jurassic Gypsum Spring Formation. For example, the Nugget Sandstone, which directly overlies the Popo Agie, is 100-400 feet thick in southeastern Jackson Hole (Love, Keefer, and others, 1951) but thins rapidly northward and is absent 30 miles south of Yellowstone National Park. (See photograph, p. 220, Wyoming Geological Association, 1956.) The presence, in the southern Yellowstone area, of a sandstone that is lithologically identical to the Nugget and in the same stratigraphic position (between the Popo Agie Member of the Chugwater Formation below and the Gypsum Spring Formation above) is quite unexpected. "Islands" of Nugget Sandstone separated by many miles from the main body of the sandstone, are known, however, in other areas, such as the southeastern part of Bighorn Basin. Because this sandstone is below a 10-foot red siltstone bed which underlies the gypsum bed or breccia of the Gypsum Spring Formation, and if the sandstone is actually a Nugget equivalent, then the red siltstone more logically should be the basal unit in the Gypsum Spring rather than the topmost unit of the Popo Agie Member of the Chugwater.

The Popo Agie Member is only about half as thick in the northern sections as in the southern sections. Distinctive beds, such as the ocher-colored analcitic claystone beds near the top of the Popo Agie in the sourthern sections, are cut out farther north beneath the unconformity at the base of the Gypsum Spring Formation.

There is no unconformity at the base of the Chugwater Formation in this area. The only fossils found in the formation are sparse unidentifiable bone fragments in the Popo Agie Member. However, the Chugwater is considered to be Triassic on the basis of vertebrate fossils found in it in the Wind River basin of central Wyoming (Colbert, 1957).

JURASSIC SYSTEM

GYPSUM SPRING FORMATION

The Gypsum Spring Formation is a thin, generally poorly exposed sequence of snowy-white gypsum, gray thin earthy dolomite beds, limestone and dolomite breccia, and red siltstone and claystone. Because of leaching, the gypsum beds are absent in most outcrops. Where present, however, they form conspicuous white patches along the slopes and ridges (fig. 7). The carbonate breccia is believed to be residuum that resulted from near-surface leaching. As shown by wells in areas to the south in Jackson Hole, the breccia merges downdip with unaltered gypsum and anhydrite. The following sections show the lithology of the formation.



Figure 7.—White gypsum bed about 15 feet thick in lower part of Gypsum Spring Formation. Basal unit in formation is a red shale 10 feet thick, at left of shovel. Hammer marks one of several leached cavities in gypsum. This is one of two known places in southern Yellowstone National Park where the gypsum bed has not been completely leached out on exposures. Photograph by J. D. Love, July 29, 1972.

Section measured 13,500 feet east of the South Entrance of Yellowstone National Park and 800 feet south of southern boundary of the park (measured by J. D. Love, J. L. Weitz, and R. K. Hose, August 1949):

The state of the s
"Lower Sundance" (part): Thickness (feet)
8. Limestone, light-gray, hard, dense, massive; contains small pelecypods
Arbitrary contact between "Lower Sundance" and Gypsum Spring Formation.
Gypsum Spring Formation:
6. Claystone, greenish-gray, limy, soft, plastic
 Siltstone, brownish-red, shaly, limy, soft, blocky; contains light-gray geodes lined with quartz crystals
4. Siltstone, brownish-red, poorly exposed 4
Gypsum and limestone breccia, light-gray, spongy; composed of calcium carbonate and a lesser amount of gypsum. 184-
gypsum 13+
2. Shale, dark-red, silty, blocky2
Total thickness of Gypsum Spring Formation27+
Contact between Gypsum Spring and Chugwater Formations is arbi-
trarily placed at top of covered interval; however, on the basis
of the section along the Snake River, it could be 5-10 feet below
the top of the covered interval. (See discussion of Triassic rocks.)
Chugwater Formation (part):

The following composite section was measured in part (units 1 and 2) on the crest of a high ridge 2,000 feet northwest of VABM Snake triangulation station, elevation 9,213 feet, 5,000 feet north of the southern boundary of D. Love, Aug. 24, 1949):

Yellowstone National Park, and in part (units 3-4) 1,700 feet southeast of units 1-2 (measured by J. D. Love, J. L. Weitz, and R. K. Hose, 1945 and 1949):

Thicknes (feet)

"Lower Sundance" (part):

Contact between "Lower Sundance" and Gypsum Spring Formation. Gypsum Spring Formation:

- 3. Gypsum, snowy-white, finely crystalline, (fig. 7); at the offset section 1,700 ft to the southeast, this unit is a light-gray breccia with red angular blocks of shale in a gypsiferous limy matrix; thickness uncertain because gypsum may have been leached from both sections...... 15+

Contact between Gypsum Spring and Chugwater Formations. Chugwater Formation (part):

Approximately 6 miles northeast of the section described above is another exposure of the Gypsum Spring Formation, at the head of a steep ravine 3,200 feet due north of the east edge of Basin Creek Lake (measured by J. D. Love, Aug. 24, 1949):

Thickn (feet)

"Lower Sundance" (part):

Contact between "Lower Sundance" and Gypsum Spring Formation. Gypsum Spring Formation:

Contact between Gypsum Spring and Chugwater Formations sharp and marked by abrupt change in lithology.

Chugwater Formation (part):

1. Siltstone and fine-grained sandstone, red and gray, blotched, irregularly bedded, moderately soft 1

The original thickness of the gypsum bed is not known because of its susceptibility to solution. In addition to the localities already discussed, one more occurrence of gypsum was observed. It is along the south bank of the Snake River near BM 7035, about 10,000 feet southeast of the mouth of Red Creek. About 20 feet of white finely crystalline gypsum is present between Triassic red beds below and oolitic fossiliferous dark-gray to black hard limestone in the "Lower Sundance" above.

Another lithologic feature, in addition to gypsum, that is common to the Gypsum Spring here and in the type locality (Love, 1939) 80 miles to the southeast in the Wind River basin, is the presence of pink siliceous geodes lined with quartz crystals in claystones above the gypsum bed. Lithologic criteria used to distinguish the Gypsum Spring from the "Lower Sundance" are discussed in connection with the Sundance Formation.

The unconformity at the base of the Gypsum Spring Formation has already been described. A slight disconformity of regional extent is present at the top of the formation. No identifiable fossils were found in the Gypsum Spring in southern Yellowstone National Park, but, because of its distinctive lithology, the sequence can be correlated with the Gypsum Spring Formation along the west side of the Wind River basin, where a rich and varied marine fauna was obtained from several sections (Love, Johnson, and others, 1945). These were identified by Imlay (1945; 1967) as Middle Jurassic.

Although the Gypsum Spring Formation was mapped separately in the field, it has been lumped, because of its thinness, with the Sundance Formation on the geologic map (pl. 1).

SUNDANCE FORMATION

The Sundance Formation is exposed only in the western part of the mapped area, on Huckleberry Ridge, and along Red and Basin Creeks. It consists of the same two map-

pable units, "Lower Sundance" and "Upper Sundance" that were described in southern Jackson Hole and in the Wind River basin of central Wyoming by Love, Tourtelot, Johnson, and others (1945) and by Love, Keefer, Duncan, Bergquist, and Hose (1951). These terms are used informally in southern Yellowstone National Park and have been recognized in some other places (Imlay, 1967). Because of the scale of the geologic map (pl. 1) and the thinness of the "Upper Sundance," however, the two sequences plus the Gypsum Spring Formation are lumped into a single cartographic unit.

The "Lower Sundance" is 350-400 feet thick and consists of interbedded shale and limestone in the lower part and highly calcareous shale in the upper part. Much of the rock is soft, easily weathered, and very susceptible to landsliding. The "Upper Sundance," in contrast, is 70-85 feet thick and consists of resistant glauconitic very limy sandstone that typically forms ledges and low cliffs. In an outcrop along the east face of Mount Sheridan, in the northwest corner of the mapped area (pl. 1), the sandstone is highly quartzitic, owing to the metamorphic effects of igneous activity that apparently took place nearby during Quaternary time.

A complete section of the Sundance Formation was measured on Huckleberry Ridge, 13,500 feet east of the South Entrance and 1,500 feet south of the southern boundary of Yellowstone National Park (measured with plane-table control for major units and steel tape for detail by J. D. Love, J. L., Weitz, and R. K. Hose, Aug., 1949; fossils were identified by R. W. Imlay):

Thickness (feet)

Cloverly and Morrison(?) Formations (part):

Sundance" picked at the top of the marine sandstone bearing Kallirhynchia and emerald-green glauconite grains.

Sundance Formation:

"Upper Sundance":

- - 47. Limestone, gray; mottled with pink; sandy, glauconitic; contains Kallirhynchia 1
 - 46. Sandstone, light-gray, very limy, shaly, fine-grained, unevenly bedded 1
- 44. Sandstone, greenish-gray; weathers rusty; limy, fine grained, glauconitic; forms ledge......
- 43. Sandstone, greenish-gray, limy, very fine grained, shaly, evenly bedded; contains green grains; softer in lower third

Thickness	Thickness
Sundance Formation—Continued "Upper Sundance"—Continued	Sundance Formation—Continued "Lower Sundance"—Continued
41. Sandstone, olive-gray, very limy, fine-grained, cross-bedded to thin-bedded; interbedded with lesser amount of gray sandy glauconitic highly fossiliferous limestone; forms ledge	23. Silt shale, light-greenish-gray; slightly limy in lower half; grades up to ocher-colored very limy silt shale which becomes tan near top
grains	unit grades up to that of overlying unit
38. Sandstone, gray, very limy, glauconitic; fossiliferous in lower part; contains gray sandy very glauconitic limestone with abundant unidentified pelecypods; forms ledge	limy, soft
37. Siltstone, greenish-gray, limy	with two minor soft zones; upper 1 ft massive; has conchoidal fracture
limy sandstone with top 1 ft very conglomeratic; very hard and forms conspicuous ledge	Shale, light-olive-gray; weathers tannish gray, very limy, brittle, flaky
very glauconitic	fossil fragments
33. Sandstone, gray, very limy, glauconitic; numerous dark grains	fossiliferous in part; interbedded with dark-brown to bluish-gray limy "pencil shale"
31. Covered interval; probably soft sandy shale	and jointed; weathers into splintery cylindrical "paper shale" fragments; some hard ledges; a few 1- to 2-ft massive beds; numerous pelecypods and dark subrounded objects 1-2 mm in diameter resembling microfossils
29. Sandstone, greenish-gray, limy, shaly, fine-grained, very glauconitic, slightly fossiliferous	8. Shale, light-gray, silty, very limy, brittle, highly fractured and jointed; weathers to "pencil shale"; some hard
Total thickness of "Upper Sundance"	ledges; fossiliferous, containing (USGS Mes. loc. 21527) Gryphaea cf. G. planoconvexa Whitfield, Astarte cf. A. meeki Stanton, Coelastarte sp., Pleuromya subcompressa (Meek), Lima cinnabarensis Stanton, Cucullaea? haguei Meek, Camptonectes platessiformis White, Camptonectes distans Stanton, Trigonia sp., Gervillia montanaensis Meek
limestone nodular zones that are more fossiliferous than remainder of unit; collection from 60 ft above base yielded (USGS Mes. loc. 21530) Gryphaea nebrascensis Meek and Hayden, Camptonectes sp., Cucullaea' haguei Meek, Isocyprina? sp., Homomya sp., Thracia weedi Stanton, Astarte meeki Stanton	7. Limestone, light-gray; highly oolitic, with some sand grains and turquoise-green glauconite grains in center of oolites; soft; highly fossiliferous; collection from upper 1 ft (USGS Mes. loc. 21526) contains Lopha cf. L. procumbens (White), Isognomon? sp., Lyosoma sp., Camptonectes distans Stanton
27. Limestone, gray; weathers light olive gray to tan; slightly shaly, oolitic, hard; contains fossil fragments	6. Limestone, light-gray, dense, hard, slabby in lower part; dove gray, hard, brittle in massive 1.5- to 2-ft beds in upper part; 4-in. quartz crystal zone 10 in. above base; fossil collection in top 1 ft yielded (USGS Mes. loc. 21525) Gryphaea sp., and gastropods
much as 4 ft thick; unit forms conspicuous marker ledge in region; fossiliferous throughout; bedding surface at top contains many <i>Pentacrinus</i> columnals and pelecypods; <i>Lyosoma powelli</i> White (USGS Mes. loc. 21529)	5. Limestone, light-gray, clayey, slabby, thin-bedded, granular
collected 13	3. Covered interval 8

Thickness	Thickness
Sundance Formation—Continued "Lower Sundance"—Continued	Sundance Formation (part)—Continued "Lower Sundance" (part)—Continued
Total thickness of "Lower Sundance"384	10. Limestone, brownish-gray, hard, sparsely fossiliferous 10 9. Shale, red, silty
Total thickness of Sundance Formation469	8. Limestone, brown, shaly, hard, fossiliferous, with Camp-
Arbitrary contact between "Lower Sundance" and Gypsum Spring Formation.	7. Shale, light-tan, limy, flaky, with several 1-ft limestone
Gypsum Spring Formation (part):	beds; fossiliferous
 Claystone, greenish-gray, limy, soft, plastic	5. Shale, light-tan, limy, flaky
light-gray geodes lined with quartz crystals	Limestone, grayish-brown, oolitic, hard, slightly glauco- nitic, sparsely fossiliferous
Units 18-22 constitute the upper and most widespread	3. Shale, light-tannish-gray, limy
of two red marker zones that are present in the "Lower	2. Limestone, gray to buff; sparsely fossiliferous except for
Sundance" of this area. The lower red zone is not recog-	clusters of macerated fossils <u>8</u> Total thickness of measured part of "Lower Sun-
nizable here.	dance"
About 5,000 feet northeast of the foregoing section, another complete section of the "Upper Sundance" was	Contact between "Lower Sundance" and Gypsum Spring Formation.
measured on the crest of a prominent ridge at an elevation	Gypsum Spring Formation (part):
of 9,200 feet, about 1,500 feet southwest of milepost 15	1. Shale, dark-blood-red, soft
on the southern boundary of Yellowstone National Park	Three partial sections of the "Lower Sundance" and
(measured by J. D. Love, Sept. 7, 1945):	one complete section of the "Upper Sundance" were measured north of the Snake River. The closest of these to
Cloverly and Morrison(?) Formations (part): (feet)	the previously described sections is on a steep southwest-
6. Sandstone, gray, platy, fissile, very fine grained, non-	facing scarp 1,500 feet southeast of Basin Creek Lake and
glauconitic	north of a conspicuous red and blue-gray scar on the east
 Claystone, red, sandy	side of the head of Red Creek meadow. It is given because
Janustone, gray, fine-granted, shary, nongradeontie	it includes the lower red marker zone that is not present
Sharp contact between the Cloverly and Morrison(?) Formations and	in sections farther south (measured by J. D. Love, Aug.
the Sundance Formation. Sundance Formation (part):	28, 1949):
"Upper Sundance":	Sundance Formation (part): Thickness
 Sandstone, greenish-gray, fine- to medium-grained, highly glauconitic; poorly bedded, with a 3-ft shaly 	"Lower Sundance" (part): (feet)
zone 10 ft below top; highly fossiliferous, chiefly oysters,	8. Shale, gray, "pencil type," splintery, limy, highly fossili- ferous, yielding (USGS Mes. loc. 21524) Gryphaea
most abundant near base	planoconvexa Whitfield, Isognomon sp., Camptonectes
Sandstone, greenish-gray, glauconitic; interbedded with gray highly glauconitic sandy very fossiliferous lime-	sp., <i>Pleuromya subcompressa</i> (Meek)100+ 7. Limestone, dark-brownish-gray, hard, ledgy, fossili-
stone in about equal amounts; some sandstone is fissile	ferous
and finely crossbedded	6. Shale, gray, soft, fissile 8
Total thickness of "Upper Sundance"	Limestone, gray, hard; forms conspicuous ledge; lowerft is slabby, sublithographic, earthy; remainder is mas-
"Lower Sundance" (part): 1. Limy shale and shaly limestone, bluish-gray; shale is very	sive; hard, sparsely fossiliferous, non-oolitic except for
plastic and sticky where wet; at this locality water seeps	top 3 in. which is dark gray and a mass of oolites 9
emerge from it, and these are sites of a series of elk	 Siltstone, ocher-yellow, soft, structureless, very limy Siltstone and silty shale (lower red marker zone), dark-
wallows	cocoa-red, soft, blocky, moderately well bedded; timy,
A partial section of the "Lower Sundance" was mea-	with spongy limestone nodules that look as if gypsum had been leached out of them, as much as 15 in. in
sured 7,000 feet northeast of the foregoing section, about 1,500 feet northeast of VABM Snake triangulation station,	diameter, in lower 5 ft; thickness approximate 16
elevation 9,213 feet (measured by J. L. Weitz and R. K.	2. Breccia, chalky white, composed of limestone that is
Hose, July 26, 1949):	highly effervescent in acid; irregular bed that looks as if it is a residual breccia from which gypsum had been
Sundance Formation (part):	leached 4
"Lower Sundance" (part):	1. Limestone, gray, a mass of brown small oolites with
11. Shale, gray; weathers light bluish tan; limy, flaky; same	abundant Trigonia, oysters, and other fossils4+
as unit 28 in previous section; fossiliferous; yielded (USGS Mes. loc. 21521) Gryphaea nebrascensis Meek	Total thickness of measured part of "Lower Sun-
and Hayden, Gryphaea sp., Pleuromya subcompressa	dance"
(Meek), Isognomon? sp., Cucullaea? haguei Meek,	From the site of this section, another section of the
Astarte meeki Stanton, Astarte morion Crickmay, Isocyprina? sp., Panope sp., Myopholas sp100+	

Sundance Formation—Continued

and associated strata is visible across the valley, 4,500 feet to the northwest on a steep south-facing escarpment 2,500 feet north of the west side of Basin Creek Lake (measured by J. L. Weitz and R. K. Hose, Aug. 29, 1949):

, y =	26. Shale, gray, limy, soft, f
Sundance Formation (part): Thickness	amount of gray shaly fos
"Lower Sundance" (part): (feet)	25. Oolite, gray, ledgy, fossili
11. Limestone, gray, clayey, blocky, massive, stylolitic; upper	interbedded with an equ
2.5 ft is dense and glossy on fresh surface; sparsely fos-	limestone with same type
siliferous 8	24. Shale, olive-gray, very limy,
10. Limestone, gray, clayey; thin-bedded, with very even	stone bed near top
bedding planes; weathers to flat plates like roofing	23. Limestone, dark-gray, oolit
shingles; manganese(?) dendrites on bedding surfaces;	scaphopods, pelecypods,
forms minor ledge	22. Shale, olive-gray, soft
9. Siltstone, pale-olive; light-ocher color in upper 7 in.;	21. Shale, gray, oolitic; dark-gr
slightly limy, soft	20. Limestone, gray; dense to
8. Claystone, silty, and silty claystone; grayish red (lower	ft; very hard; stylolitic in
red unit), with several thin light-gray-green partings;	veinlets
very limy, soft, finely blocky; in upper 2 ft, color grades	19. Claystone, ocher to light-g
up to dull reddish brown	ens and thins along of
7. Claystone, gray to pale-olive, very limy, soft; lower 6 in.	unit is irregular; underl
is harder and green and weathers yellow	stone, which, in turn, is
6. Shale, gray to dark-gray, limy, soft, flaky	limy claystone
5. Limestone, gray, shaly in part, massive in part; minor	
ledges formed by alternating 1-ft shaly and massive beds;	18. Claystone, pale-olive; has
very fossiliferous in part9	strike; slightly silty, limy
4. Shale, gray to olive-gray, limy, soft	17. Claystone, grayish-red (to
3. Siltstone, gray; weathers light olive gray; very limy, highly	mottled with pale olive
fractured; weathers to "pencil shale" on outcrops 17	to that of overlying un
2. Limestone, light-gray; upper part is highly oolitic, very	brittle
fossiliferous, identical with unit 7 in the complete sec-	16. Claystone, pale-olive, sligh
tion on Hucklebery Ridge; lower part not detailed, but	15. Claystone, grayish-red; m
lithology is similar to that of units 4-6 in Huckleberry	grades up to that of o
Ridge section	blocky
1. Covered interval5	14. Claystone, pale-olive; color
Total thickness of measured part of "Lower Sun-	unit; slightly limy, block
dance"117	13. Claystone, light-gray, very
Contact between "Lower Sundance" and Gypsum Spring Formation	12. Claystone, pale-olive; weat
arbitrarily placed at base of covered interval.	limy, blocky in part; wea
Gypsum Spring Formation not measured.	 Claystone, grayish-red; mo
o)pour oping romation not measured.	pale olive; color grades
The upper part of the "Lower Sundance," including	limy, blocky in part; wea
the upper red marker zone (units 11–17 in the following	10. Claystone, pale-olive; colo
section), was measured about 1,000 feet north of the sec-	lying unit; limy, block
	rounded blocks
tion just described; the site is on a steep east-facing scarp	9. Shale, gray, darker near
3,600 feet north of Basin Creek Lake (measured by J. L.	throughout; abundant fo
Weitz and R. K. Hose, Aug. 29, 1949):	8. Limestone, gray, very shaly
,	7. Shale, dark-brown to gray,
Sundance Formation (part): Thickness	6. Limestone, gray, shaly, sof
"Upper Sundance" (part): (feet)	Shale, gray to dark-gray; w
30. Limestone, gray, sandy shaly; has coarse light-green	per 1 ft; limy, fissile
grains which may be altered glauconite; pebbles of	4. Limestone, gray; weathers
quartzite and chert as much as one-fourth inch in dia-	fossiliferous; fresh fractu
meter; fossils include belemnites, Gryphaea, and other	third contains 1 ft of tan
pelecypods1+	3. Coquina of oysters, dark-g
Contract between "House Condense" and "House Condense"	ledge
Contact between "Upper Sundance" and "Lower Sundance."	2. Clay shale, gray; weathers
"Lower Sundance" (part):	flaky, soft; a few partii
29. Shale, gray to light-olive-gray, very limy, flaky; weathers	fossils
to typical "pencil shale"; grab samples for microfossil	1. Shale, light-olive-gray; wea
study taken at 5-ft intervals	"pencil shale"; very foss
28. Limestone, gray, massive; contains many specimens of	stone ledges
Gryphaea	Total thickness of me
to typical "pencil shale"; grab samples for microfossil	dance''
study taken from 10 ft above base to top	Underlying section not measured.
study taken from 10 it above base to top	onactiving section not measured.

ından	ce Formation—Continued	
"Low	er Sundance" (part)—Continued	
	Shale, gray, limy, soft, flaky; interbedded with equal amount of gray shaly fossiliferous limestone	3
24.	interbedded with an equal amount of gray very dense limestone with same type of bedding	2
23.	Limestone, dark-gray, oolitic, hard, thin-bedded; contains scaphopods, pelecypods, and columnals of <i>Pentacrinus</i>	3
	Shale, gray, soft	1 1
20.	Limestone, gray; dense to oolitic, very oolitic in top 3 ft; very hard; stylolitic in lower part; many thin calcite veinlets	17
19.	Claystone, ocher to light-gray, mottled, contorted; thickens and thins along outcrop; contact with overlying unit is irregular; underlain by 6 in. of gray silty limestone, which, in turn, is underlain by light-tan to ocher limy claystone	2
18.	Claystone, pale-olive; has a few red mottled zones along strike; slightly silty, limy, blocky	11
17.	Claystone, grayish-red (top of upper red marker zone); mottled with pale olive in lower part; color grades up to that of overlying unit; slightly silty, slightly limy, brittle	7
16.	Claystone, pale-olive, slightly limy, blocky	7
	Claystone, grayish-red; mottled with pale olive; color grades up to that of overlying unit; slightly limy, blocky	5
14.	Claystone, pale-olive; color grades up to that of overlying	_
19	unit; slightly limy, blocky	5 5
	Claystone, pale-olive; weathers rusty on surface; slightly	9
11.	limy, blocky in part; weathers to subrounded blocks Claystone, grayish-red; mottled with minor amount of pale olive; color grades up to that of overlying unit;	8
10.	limy, blocky in part; weathers to subrounded blocks Claystone, pale-olive; color grades up to that of over- lying unit; limy, blocky in part; weathers to sub-	7
	rounded blocks	3
9.	Shale, gray, darker near top, limy, flaky, fossiliferous throughout; abundant fossils in upper half	8
8.	Limestone, gray, very shaly, soft	l
	Shale, dark-brown to gray, limy in part, soft, flaky	2
	Limestone, gray, shaly, soft, fossiliferous	1
4.	per 1 ft; limy, fissile Limestone, gray; weathers light olive tan; very shaly, very fossiliferous; fresh fracture is dull; forms ledge; middle	4
3.	third contains 1 ft of tan to brown shale	8
	ledge	1 2
1.	Shale, light-olive-gray; weathers light gray; limy, typical "pencil shale"; very fossiliferous; contains a few lime-stone ledges	50+
	Total thickness of measured part of "Lower Sundance"2	88+

Units 11–17 compose the upper red marker zone. No thickness of the "Upper Sundance" could be obtained here, but 2 miles to the north-northeast, on the east face of Mount Sheridan, 2,500 feet west-northwest of Sheridan Lake, the sequence forms a cliff 60–75 feet high, and that is its approximate thickness. The sandstone there has been secondarily altered to quartzite. As mentioned previously, this may be the result of proximity to Quaternary igneous activity. Glauconite, oolites, and fossils, however, are not megascopically altered, but oxygen analysis of one limestone shows isotopic alteration (Love and Keefer, 1969a, p. D128).

Regional studies of the Gypsum Spring and Sundance Formations in Jackson Hole and central Wyoming show several consistent lithologic differences. These are mentioned because the remnant of the Gypsum Spring in southern Yellowstone National Park is so thin that without data in adjacent localities the question might be raised as to whether the sequence might be merely a facies of the "Lower Sundance." Dolomites are confined to the Gypsum Spring and oolites to the Sundance. Marine fossils are present in both formations, but the shell preservation is very different. Shells in the Gypsum Spring are dull and earthy and tend to be extensively leached or altered; those in the Sundance are generally little altered and are well preserved in most beds. Geodes lined with quartz crystals are characteristic of the Gypsum Spring and are rare or absent in the Sundance. Red beds and gypsum are present in both formations and, thus, are not regionally useful criteria. The remarkably continuous (other than in localities of surficial leaching) basal gypsum bed in the Gypsum Spring might be the one significant exception.

In southern Yellowstone National Park, the "Upper Sundance" can easily be distinguished from the "Lower Sundance" on the basis of glauconite. Glauconite is present throughout the "Upper Sundance" and is absent in the "Lower Sundance," except for one zone near the base. (See detailed sections.)

The unconformity at the base of the Sundance Formation has been discussed. No unconformity or disconformity was observed between the "Upper Sundance" and "Lower Sundance." The top of the "Upper Sundance" is marked by an abrupt change in lithology but not by a conspicuous erosional break.

In addition to the fossils listed in the foregoing discussion, three zones of ammonites were found in a section of the "Lower Sundance" 8,700 feet northwest of Basin Creek Lake and 1,900 feet southeast of point 9241, Huckleberry Mountain quadrangle (USGS Mes. Locs. 21522 and 21523). *Cadoceras shoshonense* Imlay was collected 30 feet below the base of the "Upper Sundance," and *Cadoceras* sp., 40 and 45 feet below the base.

The age of the "Lower Sundance" is in part Middle Jurassic and in part Late Jurassic. R. W. Imlay (written

commun., Nov. 17, 1949) discussed the age of the various collections as follows:

Most of the species of pelecypods listed occur in both the Middle Jurassic and the Callovian. According to my observations, Gryphaea nebrascensis Meek and Hayden, found in lots 21530 and 21521, does not occur below the Callovian. Also, Gryphaea planoconvexa Whitfield, found in lot 21524, does not occur above the lower part of the Middle Jurassic. Lot 21527 is probably also basal Middle Jurassic, as it contains fragmentary Gryphaea resembling G. planoconvexa, a species of Coelastarte that is widespread in the Sawtooth Formation in Montana, and Gervillia montanaensis Meek, which I have not found above the Middle Jurassic. Lots 21523 and 21522 contain Cadoceras identical with forms in the lower part of the Rierdon Formation in Montana and in equivalent beds near Cody, Wyoming. Cadoceras shoshonense, which occurs in lot 21522, has been found at many places in the zone of Gowericeras subitum directly above beds containing Arcticoceras.

Thus, in the Huckleberry Ridge section, the beds at least up through unit 9 are Middle Jurassic, as is the entire section through unit 8 in the sequence described from the locality 1,500 feet southeast of Basin Creek Lake. The sections in southern Yellowstone National Park can be correlated with the Lower Slide Lake section, 35 miles south of the park (in and adjacent to secs. 32 and 33, T. 43 N., R. 114 W.). This section, in turn, is used in regional correlations with areas to the southwest and southeast (Imlay, 1967; Love, Keefer, and others, 1951; Love, Tourtelot, and others, 1945).

The "Lower Sundance" is a stratigraphic equivalent of the Twin Creek Limestone, exclusive of the Gypsum Spring which, in westernmost Wyoming, Imlay considered to be the basal member of the Twin Creek. He (written commun., 1973) suggests the following correlation of units in the Huckleberry Ridge section with his members of the Twin Creek Limestone: Units 4–7, Sliderock Member; 8–15, Rich Member; 16–22, Boundary Ridge Member; 24–27, Watton Canyon Member; and unit 28, Leeds Creek Member.

In central Wyoming, the unconformity at the base of the Sundance cuts out successively older strata in the Gypsum Spring Formation from west to east (Love, Tourtelot, and others, 1945). The "Upper Sundance" is of Late Jurassic age and correlates with the Stump Sandstone of westernmost Wyoming.

JURASSIC AND CRETACEOUS SYSTEMS

MORRISON(?) AND CLOVERLY FORMATIONS UNDIVIDED

The Morrison(?) and Cloverly Formations are generally described and mapped as a single stratigraphic unit in central and northwestern Wyoming (Love, Thompson, and others, 1945; Love, Keefer, and others, 1951; Love, 1956a). In central Wyoming, this predominantly nonmarine sequence contains fossils of Late Jurassic age below a widespread conglomerate and (or) quartz crystal sandstone zone near the middle of the sequence, and of Early Cretaceous age above the base of this zone. In northwestern Wyoming, however, this twofold division is not as clearcut. Furthermore, the presence of nonmarine Jurassic

strata (Morrison) has not been confirmed paleontologically anywhere in the Jackson Hole region (Peck, 1956, p. 95) or southern Yellowstone National Park.

Except for a small window where the Snake River crosses the crest of the Wolverine anticline, all the exposures of the Cloverly and Morrison(?) Formations are in the western part of the mapped area. They are characterized by interbedded shale, claystone, siltstone, and sandstone in the lower 465-500 feet and by thin-bedded to massive sandstone and quartzite in the upper 100-150 feet. The shale and claystone are soft and plastic when wet; hence, their outcrops are the sites for extensive landslides along steep slopes at the east end of Huckleberry Ridge and in Red Creek and Basin Creek valleys. In exposures near Mount Sheridan the upper unit, commonly termed informally the "rusty beds member" of the Cloverly Formation, is highly quartzitic and forms conspicuous cliffs; the member represents part of the sequence that was designated the Sheridan Quartzite by Hague and others (1896) and considered by them to be Precambrian in age (fig. 6).

A generalized section of the Cloverly and Morrison(?) Formations, measured along the west slope of Basin Creek valley approximately 3 miles south of Mount Sheridan (measured by W. R. Keefer and G. O. Linkletter, 1967) follows:

Thickness Thermopolis Shale (not measured). Cloverly Formation: Rusty beds member: 19. Quartzite and sandstone, gray and brown, thin-bedded; 18. Quartzite, gray to brown and reddish-brown, fine-grained, massive, hard; forms conspicuous cliff....... 84 Total thickness of rusty beds member...... 150 Cloverly and Morrison(?) Formations undivided: Lower part: 17. Covered interval; apparently underlain largely by red, purple, and gray shale......42 16. Limestone, white, slabby; concretionary in part; forms conspicuous white ledge along slope 21 15. Shale and claystone, red and purple; contains scattered gray limestone concretions as much as 6 in. in diameter; contains a few thin beds of gray nodular limestone in 14. Limestone, gray, nodular..... 13. Shale and claystone, red and purple; contains lenses or masses of yellow claystone that form a distinctive yellowish-tan band along weathered slopes...... 12 12. Shale and claystone, red and purple; contains gray limestone concretions as much as 1 ft in diameter in upper 11. Covered interval; apparently underlain chiefly by red and purple shale and claystone..... 57 10. Sandstone and quartzite, gray, fine-grained, ledgy; in beds 9. Claystone, red, purplish-red, and gray; contains some thin hard ledgy beds of gray, brown-weathering calcareous siltstone; poorly exposed in part...... 76

Cloverly and Morrison(?) Formations undivided—Continued
Lower part—Continued
8. Siltstone, pale-grayish-green; weathers brown; thin bedded, calcareous, sandy in part; forms ledge
thin beds of hard, rusty-brown-weathering calcareous siltstone
 Sandstone, pale-green to gray, very fine grained, thin- bedded to slabby, silty, soft; contains abundant secondary calcite that fills small cracks; poorly exposed in part 23
5. Sandstone, white to gray; weathers rusty brown in part; very fine grained; in beds 6 in. to 1 ft thick; porous,
slightly friable; contains sparkly grains
lain mostly by soft shale, claystone, and siltstone 96 3. Shale, claystone, and siltstone interbedded, gray, pale-
green, and purple
Shale and claystone, gray, grayish-green, red and purple; calcareous in part
Total thickness of lower part of Cloverly and Morrison(?) Formations undivided
Total thickness of Cloverly and Morrison(?) Formations

Thickness

A partial section of the Cloverly and Morrison(?) Formations was measured with plane-table control for major units and steel tape for detail by J. D. Love, J. L. Weitz, and R. K. Hose, Aug., 1949 on the north end of Huckleberry Ridge 13,500 feet east of the South Entrance and 2,000–3,000 feet south of the southern boundary of the park. A thrust fault cuts the upper part of the variegated sequence above unit 56.

Thickness (feet) Cloverly and Morrison(?) Formations (part): 56. Sandstone light-tannish-gray; sparkly on fresh surfaces; limy, fine grained, clean, sparse dark grains, crossbedded to thin bedded to massive, highly fractured; 55. Covered interval 5 54. Claystone, drab-greenish-gray, silty..... 53. Marlstone, light-gray; weathers light olive gray; silty; weathered surface looks like chamois skin; breaks up into blocks like paving stones...... 2 52. Claystone, drab-gray, silty 51. Siltstone, gray, limy, hard; breaks up into blocks like 50. Covered interval 10 49. Claystone; gray and silty in upper part; gray thin-bedded sandstone in middle; red silty claystone in lower part... 5 48. Claystone, grayish-red, silty...... 6 46. Sandstone, grayish-red, fine-grained, evenly bedded...... 5 45. Covered interval, probably sandstone and claystone 13 44. Sandstone, light-greenish-gray, shaly, limy, very fine grained, soft; interbedded with equal amount of grayish-red to pale-brown silty limy claystone; top 1 ft is sandstone ledge..... 43. Sandstone; light greenish gray, with slight mottling of grayish red; limy, very fine grained, soft.....

	Thick	knes
Cloverly	and Morrison(?) Formations (part)—Continued (fee	et)
	Claystone, variegated, greenish-gray and grayish-red, silty, limy; 1-ft ledge of grayish red very shaly limy len-	
	ticular sandstone 5 ft above base	11
41.	Sandstone, grayish-red, shaly, limy, thin-bedded, soft; interbedded with lesser amount of gray shaly limy thin-bedded soft sandstone	5
40.	Claystone, variegated, greenish-gray, pale-brown, grayish-	
20	red; silty	5
33.	even bedding	6
38.	Claystone, light-green and pale-brown to grayish-red; mottled and interbedded; red predominates; limy; harder in upper middle; upper part is sandy, soft, and grades up to overlying unit	11
	Concretionary bed; matrix is of greenish-gray and gray- ish-red mottled limy claystone; concretions are of grayish red irregularly shaped limestone, \(\) in. in longest dimension; 2-ft bed of grayish-red and light-green mottled silty clayey limestone 4.5 ft above base	
36.	Covered interval	10
35.	Sandstone, greenish-gray and grayish-red, mottled, limy, very fine grained; forms minor ledge	1
34.	Claystone, pale-brown to grayish-red; green mottling, silty, slightly limy	2
33.	Sandstone, grayish-red, very shaly, limy in part, hard to soft; contains sparse gray-green limy masses	3
32.	Covered interval	9
	Claystone, pale-brown to grayish-red, silty	3
	Limestone; light gray in upper part; pale brown to gray- ish red in lower part; very shaly; breaks up into slabs	
29.	like paving stones; forms ledge	1
28	Siltstone, brown, hard; top 3 in. is olive gray	2
	Sandstone, greenish-gray, limy, very fine grained; breaks	
26.	up into slabs like paving stones	1
25.	grayish red, siltySandstone, grayish-red; mottled with light olive gray in	2
24.	part; shaly, limy, very fine grained; forms ledge	3
23.	three 6-in. olive-gray siltstones	5
	silty, brittle, and hard	1
	Claystone, pale-brown to grayish-red, silty	2
21.	Poorly exposed interval; probably claystone, pale-brown	-
20.	to grayish-red, siltySandstone, grayish-red, shaly, very limy, very fine grained, hard; forms ledge	5
19.	Sandstone, light-olive-gray, shaly, limy, very fine grained, thin-bedded	1
18.	Claystone, brownish-red, silty, slightly limy, hard, brittle; contains half-inch-thick green sandy partings	3
17.	Sandstone, light-olive-gray, limy, very fine grained; moderately soft, but forms minor ledge	1
16.	Claystone, brownish-red, silty, slightly limy; contains half-inch-thick green sandy partings	
15.	Sandstone, light-olive-gray, limy, very fine grained;	4
14.	appears to be lenticular; forms minor rounded ledge Claystone, brownish-red, silty, soft; 1-ft-thick green shaly sandstone bed 3.5 ft above base; 1-ft-thick green silty	2
	claystone in middle; upper 3 ft contains many laminae	
	of brown sandstone	15

	Thickne
Cloverly and	(feet) Morrison(?) Formations (part)—Continued
13. Sand	lstone, olive-gray, limy, very fine grained, moderately
m	stone; greenish gray in lower part; brownish red in iddle; and olive green at top
ha	dstone, olive-gray, slightly shaly, limy, fine-grained,
10. Shall	e, gray, sandy, limy
9. Clay	stone, grayish-red, silty
8. Silt	shale, gray, limy; sandy in top 1 ft
fir	dstone, light-olive-gray, shaly in part, limy, very me grained
6. Silts	tone, olive-gray, blocky, unevenly bedded
5. Clay	stone, grayish-brown to grayish-red, limy 1
si	ered interval; probably reddish-brown-claystone or Itstone
	dstone, gray, limy, very hard, very fine grained
2. Part	ly covered; pits indicate claystone, gray, silty

Contact between Cloverly and Morrison(?) Formations and Sundance Formation picked at the top of the uppermost marine sandstone containing emerald-green glauconite grains and the brachiopod *Kallirhynchia*.

Sundance Formation:

Several sections of the upper part of the Cloverly and Morrison(?) Formations, especially the rusty beds member, were measured. One of these is exposed on the west face of a high ridge, 6,000 feet south-southeast of Basin Creek Lake and 2,900 feet north-northwest of hill 8242, Huckleberry Mountain quadrangle. The upper 50 feet of the variegated sequence consists of fine-grained plastic lilac-colored claystone in the upper part and grayish-red claystone in the lower part, both of which contain abundant white limestone nodules and white to purple concretions as much as several feet in diameter. Above this is the rusty beds member, 100 feet thick. The lower 40 feet is quartzite and sandstone, which are white to light gray, weathering red, sparkly, hard, ripple marked, slabby, but more massive near the top. The upper 60 feet is dull green fine-grained hard slabby sandstone that weathers brown. Near the top, the sequence is siliceous, very fine grained, silty, and weathers with a chippy appearance like that of siliceous shale.

An almost identical section is exposed 4 miles to the east-northeast, where the Snake River crosses the crest of the Wolverine anticline. About 30 feet of variegated waxy claystone is at the base. It contains large gray lithographic siliceous limestone masses as much as 3 feet in diameter at the base and red to lilac-colored claystone at the top. This is overlain by a complete section of the rusty beds member, 100 feet thick, with a lithology almost identical

to that southeast of Basin Creek Lake. The most spectacular feature of this section is the presence of broad bedding-plane surfaces which show many types of well-preserved ripple marks (fig. 8).

A few small polished pebbles ("gastroliths"?) of red, gray, and black chert are present in some of the claystones, but nowhere are they abundant.

About 3,500 feet northwest of Basin Creek Lake the basal part of the Cloverly and Morrison(?) Formations is exposed (section measured by J. D. Love, Aug. 25, 1949):

1 (,	-1.
	Thick	ness
Cloverly and Morrison(?) Formations (part):	(feet)
5. Claystone, green and red, mottled, blocky; contains s	some	
hard nodular limy beds	15-2	20
4. Limestone, gray, silty, blocky		2
3. Limestone, blue-gray; contains pelecypods, several for		
of gastropods, and possibly ostracodes and chara,	but	
it is so dense, hard, fine grained, and brittle that	the	
fossils are difficult to break out for identification		3
	_	
Total thickness of measured part of Cloverly	and	

Thickness (feet)

Sharp contact between Cloverly and Morrison(?) and Sundance Formations.

Sundance Formation (part):

The fossils in unit 3 of this section are among the few found in the Cloverly and Morrison(?) sequence. Two small collections of fossils were obtained from the faulted section on Huckleberry Ridge; both occur above that part of the section described earlier in this report. The lower of these two collections consists of ostracodes from a white limestone nodule zone probably in the middle of the variegated part of the sequence. The following forms were identified (F. M. Swain, written commun., Jan. 11, 1947): Cypridea compta Peck (recorded by him from the lower part of the Bear River Formation and Draney Limestone); Cypridea anomala Peck (recorded by him in the lower part of the Bear River, Draney, and Kootenai Formations); Cypris sp., and "a new ostracode genus?, tiny, smooth,

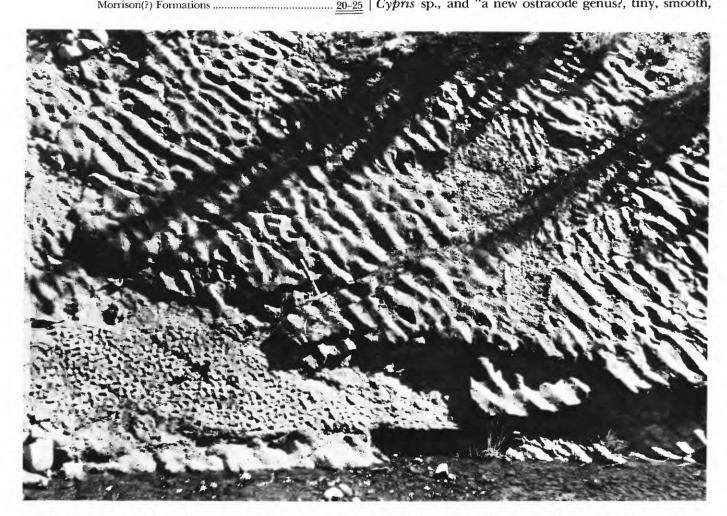


FIGURE 8.—Dip slope of hard brown sandstone in rusty beds member of Cloverly Formation, showing characteristic ripple marks, on west flank of Wolverine anticline where it is crossed by the Snake River (foreground). Photograph by J. D. Love, Sept. 1, 1949.

a cyprid." These forms are characteristic of rocks of Early Cretaceous age farther south in Wyoming.

The upper collection consists of gastropods from a 6-foot-thick dense hard pyrite-bearing buff limestone in the variegated sequence about 40 feet below the rusty beds member. Neither this collection nor the one cited above from unit 3 has been identified, but similar forms from the variegated beds farther south in Jackson Hole (Love, Hose, and others, 1951) are of Early Cretaceous age.

No evidence of unconformities is known either at the base, top, or within the Cloverly and Morrison(?) Formations of this area. The rusty beds member is overlain by the soft black Thermopolis Shale. In places, because the lithologies are gradational through several feet of strata and the exposures are commonly very poor, the contact is mapped where the topography changes from ledges below to soft shaly covered slopes above.

CRETACEOUS SYSTEM

THERMOPOLIS SHALE

The Thermopolis Shale consists of either two or three members throughout most of central and northwestern Wyoming: a lower black shale member, the Muddy Sandstone Member, and, in some places, an upper black shale member. In most areas the upper shale is difficult to distinguish from the overlying Mowry Shale because lithologies are similar, the contact is gradational, and the shale units are poorly exposed. For these reasons, the upper member of the Thermopolis, where present, is generally combined with the Mowry for purposes of stratigraphic discussion and detailed geologic mapping (Love, Keefer, Duncan, and others, 1951; Keefer, 1957, p. 182). Within the area of present study, however, all Thermopolis and Mowry strata were mapped as a single unit. The Muddy Sandstone Member is highly quartzitic and forms conspicuous cliffs in exposures south of Mount Sheridan; it was included in the Sheridan Quartzite by Hague and others (1896), and thought by them to be of Precambrian age.

The Muddy Sandstone Member ranges in thickness from about 60 feet, 4,000 feet south of milepost 14, to more than 100 feet, 6,000 feet south-southeast of Basin Creek Lake (frontispiece, *B-B'*).

A good exposure of the lower black shale member was measured on the west face of a high burned-over ridge 6,700 feet south-southeast of Basin Creek Lake and 2,300 feet north-northwest of hill 8242, Huckleberry Mountain quadrangle (measured by J. D. Love, Aug. 28, 1949). The Muddy Sandstone Member was measured south-southwest of the black shale section, on a sheer 100-foot face of a prominent west-projecting point (measured by J. L. Weitz and R. K. Hose, Aug. 28, 1949).

Thick	ness
Mowry Shale and (or) upper black shale member (fee of Thermopolis Shale:	et)
 Silt shale, dark-gray, soft, paper thin in part; sparse thin dark-gray shaly siltstone beds; forms slope 	10+
Contact between Muddy Sandstone Member and overlying shale quence arbitrarily picked at this horizon. Muddy Sandstone Member:	e se-
 24. Siltstone, dark-greenish-gray, shaly, fucoidal in part; fractures into ragged fragments; lower half forms slope; upper half crops out as jointed ledges 23. Silt shale, dark-gray; weathers olive gray; soft; splits into paper-thin flakes; sparse thin shaly siltstone beds; 	
forms slope	
21. Silt shale, dark-gray, soft, brittle	3
20. Siltstone, olive-gray; weathers rusty; blocky, thin bedded; contains a few shale laminae	13
bedded with olive-gray thin-bedded siltstone; yellow- brown ironstone parting 1 ft above base	3
layers	2
17. Silt shale interbedded with equal amount of shaly gray siltstone; weathers dark brown; unit in thin regular beds; forms ledges; quartzite parting 1 ft below top	4
16. Quartzite, light-gray; weathers rusty; fine grained, very hard	1
Silt shale, light-gray; sandy in part Quartzite, light-gray; weathers rusty; fine grained, very hard	1 2
13. Siltstone, olive-gray; weathers rusty brown, shaly in lower half; thin bedded, with uneven bedding planes	6
12. Siltstone, gray; weathers dark rusty brown; sandy; evenly bedded, in beds 3-4 in. thick, interbedded with gray silt shale; 6 in. of light-gray to white clean hard quartatitic sandstone at top	6
11. Sandstone, gray; weathers dark rusty brown; very fine grained in upper part; lower part has olive-gray thin- bedded siltstone in about equal amount to sandstone;	
6-in. light-gray quartzite 1 ft below top	6
faces; very fine grained, massive to thin bedded 9. Sandstone, olive-drab; has black shale partings, very silty, very fine grained, hard, noncalcareous, massive	2 _1
Total thickness of Muddy Sandstone Member	93
Lower black shale member of Thermopolis Shale: 8. Siltstone, black, poorly bedded, nodular, blocky; irregular partings of dark-olive-drab siltstone and sandstone 7. Shale and claystone, dark-gray; about one-fourth of unit is limy hard siltstone, in 1- to 3-in. beds in lower and upper parts of unit, with some siltstone near middle; 1-ft creamy-tan biotitic bentonite bed 3 ft below top;	20
upper part of unit slumped	55 1
Shale, dark-gray, silty, soft; contains minor ledges of irongray hard siltstone near top and base of unit	8

Thickness

Inicaness
Lower black shale member of Thermopolis Shale—Continued (feet)
4. Sandstone, iron-gray, silty, limy, hard, massive; forms conspicuous ledge I
3. Shale, dark-gray, silty, soft; interlaminated with iron-gray slightly limy hard siltstone in beds as much as 2 in. thick
2. Shale, black, flaky, soft, very fine grained, fissile; poorly exposed in top 20 ft; upper part dark gray, more silty, and less fissile
Total thickness of lower black shale member of Thermopolis Shale <u>I71</u>
Contact between Thermopolis Shale and Cloverly Formation marked by sharp change in lithology. Cloverly Formation (part):
, ,
Rusty beds member (part):
1. Sandstone, dull green; weathers brown; fine grained,
hard, slabby; upper part weathers to resemble chippy
siliceous shale
The Thermopolis Shale is conformable with overlying
and underlying rocks. No fossils were found in it in

MOWRY SHALE, INCLUDING, WHERE PRESENT, UPPER BLACK SHALE MEMBER OF THERMOPOLIS SHALE

southern Yellowstone National Park, but farther east and southeast the Thermopolis Shale contains marine and brackish-water fossils and sparse leaves of Early Cretaceous age (Eicher, 1960; Curry, 1962; Paull, 1962).

The Mowry Shale is one of the most easily recognized units in the Mesozoic sequence of this region. It is about 650 feet thick and is characterized chiefly by gray to black hard brittle siliceous shale and siltstone that break up into small blocky chips. These weather to distinctive silverand bluish-gray colors. The regionally distributed abundant fish scales in many parts of the section also distinguish the formation. As mentioned previously, in some places the siliceous strata grade downward into soft black fissile shale of the upper member of the Thermopolis Shale, and in others, siliceous beds extend almost to the Muddy Sandstone Member. In most places the boundary between the formations commonly is too obscure to be mapped with certainty.

A section of the Mowry Shale, complete except for the basal 25–50 feet, is exposed along a steep northwest-facing escarpment on Huckleberry Ridge, 4.5 miles east-southeast of the South Entrance of Yellowstone National Park and 6,000 feet south-southeast of milepost 15 on the southern boundary of the park (section measured by J. L. Weitz and R. K. Hose, Aug. 6, 1949):

Frontier Formation (part):

50. Sandstone, light-gray, coarse-grained; abundant black grains that give rock a pepper-and-salt appearance.......11+

Contact between Frontier Formation and Mowry Shale picked at the

Contact between Frontier Formation and Mowry Shale picked at the base of the coarse-grained sandstone which has regional extent and which is much coarser grained and less siliceous than the sandstone beds in the Mowry Shale.

		ckness
Mowry	Shale (part):	eet)
	Covered interval	12
	Silt shale, gray	6
	Sandstone, light-tannish-gray, limy; forms ledge; medium	-
	to coarse grained in upper 5 ft and fine grained in	
	lower part	9
46	Siltstone, olive-yellow, bentonitic, at base; carbonaceous	J
10.	shale in middle; and olive-yellow bentonite at top	2
45	Shale, gray, sandy, soft; contains plant fragments	5
	Sandstone, gray to light-gray, pepper-and-salt appearance;	3
11.	slightly limy, fine grained, massive; contains clay pel-	
	lets; upper 6 in. contains many dark mineral grains	٥
19		8
43.	Sandstone, gray, shaly, slightly limy; interbedded with equal amount of gray sandy shale; more sandy in upper	
		7
40	half	7
42.	Shale, dark-gray to dark-brown, sandy, soft, slightly	
4.1	carbonaceous	4
41.	Bentonite, light-gray; composing basal 6 in., overlain by	
	1 ft of dark-greenish-gray hard siltstone; then 1 in. of	
	bentonite, then 1.5 ft of dark-greenish-gray hard silt-	
	stone; gray siliceous brittle silt shale at top	3
	Siltstone, dark-greenish-gray, hard	2
	Silt shale, gray, siliceous, brittle	
	Siltstone, dark-gray, soft, blocky	6
37.	Sandstone, olive-gray, limy, shaly, fine-grained; thin-	
	bedded in upper third; massive in lower part	12
	Shale, gray, sandy	2
35.	Siltstone, olive-gray, limy, thin-bedded, composing lower	
	half of unit; grades up to olive-gray fine-grained limy	
	hard tough sandstone, in beds 8-10 in. thick	6
34.	Silt shale, gray, siliceous, brittle, flaky	38
	Siltstone, with dark- and light-gray banded appearance;	
	siliceous, tuffaceous(?); in beds 6 in. thick	8
32.	Silt shale, gray, siliceous, brittle, flaky	18
	Siltstone, gray, siliceous, brittle; in beds 6 in. to 1 ft thick;	
	some parts have light-gray laminae and these weather	
	mottled dirty gray; forms ledges	10
30.	Claystone, dark-gray, silty in part, siliceous, brittle,	
	blocky; some beds have silty light-gray laminae	45
29.	Claystone, black, siliceous, hard, blocky	5
	Silt shale, dark-gray to black, siliceous, brittle	8
	Siltstone, dark-gray to black, very hard; forms ledges; in	
	beds 6 in. to 1 ft thick; breaks with conchoidal fractures	16
26	Covered interval; float suggests dark-gray siliceous silt	
_0.	shale	10
25	Siltstone, dark-gray, siliceous; has thin even bedding;	
49.		19
9.1	Sandstone, gray, very fine grained, blocky	4
93	Silt shale, dark-gray to black; minor intervals have white	•
43.	laminae	19
99	Silt shale, black, siliceous, flaky; 2-ft bed of greenish-	
24.	gray siliceous lenticular siltstone 1 foot above base	97
0.1	Sandstone, gray, siliceous, tuffaceous(?), fine-grained,	41
21.		
	hard, thin-bedded; interbedded with lesser amount of	1
00	gray siliceous silt shale	4
20.	Tuff, light-green, mottled with pink; bentonitic in part	2
	Claystone, dark-gray, silty, brittle; contains fish scales	8
18.	Sandstone, greenish-gray, very fine grained, hard	12
	Silt shale, dark-gray, siliceous	9
16.	Claystone and silt shale, dark-gray to black, siliceous,	
	brittle	20
15.	Sandstone, dark-gray; weathers silvery gray, siliceous,	
		11
14.	Silt shale, black, flaky	4
13.	Claystone, dark-gray, siliceous, hard	2

Thickness

Mowry Shale (part)—Continued 12. Silt shale, dark-gray to black, thin-bedded, soft, flaky; 2 in. of light-green bentonite 15 ft above base; 6-in. hard ledge 20 ft above base...... 24 11. Sandstone, greenish-gray, siliceous, tuffaceous, laminated; resembles a welded tuff; interbedded with lesser amount of silt shale 10 9. Claystone, gray, siliceous, massive; moderately hard in upper half; very hard and cherty in lower half..... 7. Sandstone, light-gray, fine-grained, moderately hard, evenly bedded; forms ledge; contact with overlying unit 6. Silt shale, dark-gray to black, siliceous, brittle; lower half contains a few thin beds of light-gray sandstone with black laminae; bedding planes in middle of unit are contorted, which may have some effect on interpreted 5. Sandstone, gray, tuffaceous(?), hard, tough, evenly bedded 7 4. Shale, dark-gray to black, siliceous, hard, brittle..... 3. Sandstone, gray, very fine grained, moderately hard, thin-bedded..... 1. Siltstone, dark-gray, siliceous, brittle; interbedded with an equal amount of dark-gray siliceous brittle shale; 6 in. light-gray sandy silty soft bentonite at base; 2 in. of olive-yellow soft flaky bentonite at top.....

Total thickness of measured part of Mowry Shale.....601 Underlying rocks not exposed.

Another good section of the Mowry Shale is along the east bank of the Snake River, on the northeast flank of the Wolverine anticline, about 10,500 feet southwest of the Chicken triangulation station, Mount Hancock quadrangle. This is a broad fresh exposure that shows in detail the remarkably even bedding, $\frac{1}{10}-1$ inch thick, that is not conspicuous in average weathered outcrops.

No unconformity was observed at either the base or the top of the Mowry Shale. In the Jackson Hole and southern Yellowstone National Park areas, the Frontier-Mowry contact is arbitrarily placed at the base of a widespread coarse-grained nonsilicified sandstone (Love, Duncan, and others, 1948; Love, Keefer, Duncan, and others, 1951; Love, 1956a). Many sandstone beds also occur in the upper part of the Mowry Shale but in general they are finer grained, harder, and less massive than those in the basal part of the Frontier Formation.

The Frontier-Mowry contact is considered to be the boundary between the Upper and Lower Cretaceous Series in this region (Cobban and Reeside, 1952a, b; Love, 1956a, p. 78).

FRONTIER FORMATION

The Frontier Formation consists of 800–900 feet of interbedded sandstone and shale with thin beds of bentonite, porcellanite, and sparse impure coals that are especially numerous in the lower part. The sandstone beds locally form ledges, but in general most of the strata are poorly

exposed and are extensively slumped because of the incompetence of the shales and bentonites.

The entire formation is present in only two areas of outcrop—one on the high ridge about 10,000 feet east of the mouth of Red Creek and the other on the Wolverine anticline. A thickness of about 900 feet was computed for the section on the northeast flank of the anticline, where complete exposures extend from the upper part of the Mowry through the lower part of the Frontier. The overlying beds in the Frontier are less well exposed. The basal sandstone, the same as the one described as unit 50 which overlies the top of the Mowry Shale in the Huckleberry Ridge section, consists of 6 feet of coarse-grained sandstone. It is in beds 6 inches thick, is dark gray and limy, and has large angular black grains and turquoise green glauconite(?) grains. Above the basal sandstone is a porcellanite, bentonite, and carbonaceous shale zone more than 50 feet thick, probably equivalent to a similar zone farther south in Jackson Hole (Love, Hose, and others, 1951). The porcellanites are extraordinarily fine-grained, and are composed of alternating pastel green, pink, and white laminae that give the rock a distinctively striped appearance. Some beds within the porcellanite zone contain concentrations of white pisolites as much as onefourth inch in diameter, also similar to those found in sections farther south.

Overlying the Mowry Shale section described above, 6,000 feet south-southeast of milepost 15 on the southern boundary of Yellowstone National Park, are some beds of interest in the lower part of the Frontier Formation. A reconnaissance section was measured by J. D. Love, July 26, 1972, as follows:

Frontier Formation (part): 14. Sandstone, gray, coarse-grained, massive...... 5 13. Covered interval 25 12. Sandstone, dark-green, nodular; rich in glauconite; one gray (black-coated) highly rounded chert pebble 1 in. in diameter..... 11. Claystone, brown; appears granular; has abundant unique euhedral crystals of kaolinite..... 10. Sandstone, dark-brown, fine-grained, nodular, contains black manganese(?) granules..... 9. Covered interval 60 8. Bentonite, cream-colored, impure 1 Sandstone, gray, coarse-grained; pepper-and-salt appearance...... 10 5. Rocks not described 75 4. Porcellanite, white to greenish-brown, hard, dense, brittle, evenly bedded; contains abundant and very well preserved black and dark-brown fern fronds in a white matrix 5 2. Sandstone, gray, pepper-and-salt, thick-bedded, coarsegrained......<u>15</u> Total thickness of measured part of Frontier Formation<u>257</u> Mowry Shale:

1. Silt shale, gray, soft 10+

The kaolinite crystals in unit 11 are of exceptional size and quality. They were studied by Richard Tripp, who provided the following description (written commun., 1973): "The crystals range up to 7 mm across the cleavage face, are light beige to brown in color, and generally occur as very sharp, straight-to-curved, translucent, elongated hexagonal prisms. In quality, the crystals resemble goshenite beryl. Kaolinite crystals usually occur only as microscopic scales."

Leaves, such as those in unit 4, are common in the porcellanites above the pisolite beds in this area and farther south in Jackson Hole. *Anemia fremonti* Knowlton (R. W. Brown, written commun., Dec. 12, 1949) is the most common form.

Scattered and somewhat slumped exposures of the Frontier Formation are present in huge landslide scars on the high ridge east of the mouth of Red Creek (frontispiece). The section here is of special interest because it contains several zones of diagnostic fossils. Because of the type of exposures, the section is necessarily only an approximation.

Thickness (feet)

Frontier Formation (part):

- 7. Shale, dark-gray to black, soft; has some bentonite partings near middle; very fossiliferous in lower part; ironstone concretions up to 4 ft in diameter directly below very fossiliferous black shale and above bentonite; concretions yielded the following fossils (J. B. Reeside, Jr., written commun., April 27, 1946, no USGS Cat. No.; additional collection made Aug. 4, 1949, identified by W. A. Cobban, written commun., Feb. 21, 1950, USGS Cat. No. 21505);

1946 identifications:

Inoceramus deformis Conrad Ostrea cf. O. anomioides Meek

Volsella sp. undet.

Lunatia? sp.

Anchura sp. undet.

Baculites aff. B. codyensis Reeside, but

much larger

"Hamites" sp., fragments

Scaphites ventricosus Meek and Hayden

Barroisiceras sp., juvenile

1950 identifications:

Nucula coloradoensis Stanton

Inoceramus cf. I. deformis Meek

Inoceramus n. sp.

Ostrea aff. O. anomioides Meek

Cardium pauperculum Meek

"Tellina" sp.

Cylichna sp.

Actaeon propinguus Stanton

Dentalium cf. D. gracile Hall and Meek

Baculites n. sp.

Peroniceras n. sp.

uncoiled ammonite

Thickness (feet)

Frontier Formation (part)—Continued

 Sandstone, gray, slabby, silty; has dark-gray shale and siltstone partings; fossil collection yielded (USGS Cat. No. 21507, identified by W. A. Cobban, written commun., Feb. 21, 1950):

Nemodon n. sp., aft. N. mcconnelli McLearn

Ostrea aff. O. anomioides Meek

Pholadomya coloradoensis Stanton

Cardium curtum Meek

Cymbophora emmonsi Meek

"Siliqua" sp.

	1 .	
	Parmicorbula? sp.	
	Gyrodes sp.	
	The age is probably early Niobrara	15
5.	Siltstone and shale, dark-gray, sandy	15
4.	Slumped beds; lithology uncertain	20
3.	Porcellanite zone; chiefly white, pink, and green dense	
	hard slabby porcellanite beds interbedded with black	
	carbonaceous shale and white to cream-colored benton-	
	ite beds; poorly exposed	50±
2.	Sandstone, brown, very coarse grained, slabby, poorly	
	exposed	-10

Total thickness of measured part of Frontier Forma-

Mowry Shale (part; exposed in north-facing big landslide scar at top of ridge):

1. Shale, dark-gray to black, hard, siliceous, slabby100+

A detailed section, nearly 900 feet thick, but with two covered intervals, one of 100 feet and the other of 340 feet, was measured on Arizona Creek, 6 miles south of Yellowstone National Park and 3.5 miles east of Jackson Lake (Love, Hose, and others, 1951). The porcellanite zone is recognizable, but the fossiliferous beds described above are apparently within the thickest covered interval.

The formation thins progressively from south to north through Jackson Hole, and this thinning continues northward across Yellowstone National Park (fig. 9). For example, C. W. Brown (1957) measured 416 feet on the southwest face of Mount Everts in northwestern Yellowstone National Park, 55 miles north of the section just described, and Fraser, Waldrop, and Hyden (1969) reported about 500 feet on Cinnabar Mountain, 10 miles still farther northwest. The difference in thickness of these two northern sections may be, in part, the result of different interpretations as to the Mowry-Frontier and Frontier-Cody contacts. No evidence of unconformities either at the base or at the top of the Frontier was noted. The upper contact is apparently gradational and was picked where the predominantly sandstone section grades up to predominantly shale. Regional relations indicate that the uppermost sandstones are transgressive deposits laid down during the initial westward advance of the Cody Sea into this region.

The Frontier is largely of marine origin, but the thin coals and leaves in the porcellanite beds indicate near-shore swamp environment during deposition of part of the formation. Marine fossils in both the lower-middle

and the upper parts of the formation are of early Niobrara age (Love, Hose, and others, 1951; Love, 1956a) and the base of the formation is considered to be the base of the Upper Cretaceous Series in this region.

Concerning the occurrence of *Peroniceras* in unit 7 of the section southeast of the mouth of Red Creek, W. A. Cobban commented (written commun., Feb. 21, 1950): "The presence of the ammonite *Peroniceras* at locality 21505 is of considerable interest. This is a rare genus in the American Cretaceous. Other than the Jackson Hole occurrence, it is known in the western interior only from the Mancos Shale of Santa Fe County, New Mexico. It occurs in the Austin Chalk of Texas."

CODY SHALE

The Cody Shale is predominantly gray shale with one moderately persistent marker sandstone in its upper part. The thick shale units are soft and easily weathered and in this region of extensive glaciation, steep topography, and high precipitation, the Cody outcrops are sites of many landslides. Exposures of various parts of the formation, including both the top and the bottom, are present only in the same two areas as the Frontier Formation—on the Wolverine anticline and on the high ridge about 10,000 feet west of the mouth of Red Creek.

The following section is exposed on the north side of the Snake River along the northeast flank of the Wolverine anticline at the western base of Barlow Peak (measured by J. D. Love, Sept. 3, 1949):

Bacon Ridge Sandstone (part): (fee	et)
8. Sandstone, dark-gray, slabby to nodular to massive; basal	
5 ft contains specimens of inocerami as much as 15	
in. in diameter; unit is exposed in sheer cliff on north	
bank of Snake River=	70_
Contact between Bacon Ridge Sandstone and Cody Shale exposed ald	ong
Snake River Canyon; contact is marked by sharp lithologic char	
from predominantly massive sandstone above to more silty a	
shaly and thin-bedded sandstone below. This, in turn, gra	ıdes
down to blue-gray sandy shale.	
Cody Shale:	
7. Sandstone, gray, slabby, silty, thin-bedded; harder units	
form weak ledges	30
6. Shale, blue-gray, homogeneous, evenly bedded; has some	
thin siltstone and very fine grained sandstone zones3	50±
5. Sandstone, greenish-gray, glauconitic, fine- to coarse-	
grained; angular grains; slabby, with some 2-ft massive	
ledges near top; forms conspicuous marker ledge that	
is locally useful in correlation1	00±
4. Shale, blue-gray, silty, evenly bedded; forms smooth	.
steep exposures along north side of river2	
3. Shale, blue-gray, silty, evenly bedded	00±
2. Shale, blue-gray, silty, evenly bedded; interval computed	
from topographic map and stations on air photographs,	

Gradational contact between Cody Shale and Frontier Formation, picked where sandstone below is predominant over shale above.

so may be only a very rough approximation100±

Frontier Formation (part):

Thickness (feet)

7	hickness
Bacon Ridge Sandstone (part):	(feet)
7. Siltstone, bluish-gray; weathers light gray, hard; irre	g-
ularly but evenly bedded; weathers to smooth slop	oe;
sparse beds of dark-gray shale and thin slabby san	ıd-
stones; overlying rocks not exposed but float contain	
Bacon Ridge type of sandstone containing oysters a	nd
Inoceramus	
6. Shale, black, coaly	l
5. Sandstone, light-gray; has bluish tinge because of abu	ın-
dance of black grains; massive to crossbedded, so	ft,
porous, fine to medium grained, limy; contains oyste	rs,
Inoceramus, and chert pebbles ¼ in. in diameter 30	
above base; identical to basal sandstone in Bacon Ridge	ge,
unit 8, Snake River Canyon section; base apparen	tly
transitional to underlying unit	<u>120</u>
Total thickness of measured part of Bacon Rid	ge
Sandstone	<u>241+</u>

Contact between Bacon Ridge Sandstone and Cody Shale arbitrarily placed at base of massive sandstone unit.

Cody Shale (part):

Thickness

Total thickness of measured part of Cody Shale......710 Underlying beds covered by rhyolite and alluvium.

The sandstone marker bed (unit 5 in the Snake River Canyon section of the Cody Shale) was not identified in the Outlet Creek section. The presence of chert pebbles, uncommon in sections to the south (except in unit 3, Snake River Canyon section of Bacon Ridge Sandstone, see below), indicates a new element in the post-Cody depositional story but the significance of these pebbles is not yet understood.

Brown (1957) measured about 1,275 feet of Cody Shale on the west face of Mount Everts in northwestern Yellowstone National Park (fig. 9). A field comparison of this section with that in the Snake River canyon (described above) shows that the two sections are lithologically almost identical except that there are more thin bentonites in the lower part of the Mount Everts section. At the top is the same type of sandstone zone transitional to the overlying Bacon Ridge Sandstone. Regional data indicate that isopach lines trend nearly north-south and that the Cody Shale thins westward across Jackson Hole and Yellowstone National Park at the rate of about 50 feet per mile.

There is no recognizable erosional break at the base or at the top of the Cody Shale. No fossils were collected from the Cody Shale in southern Yellowstone National Park, but farther south both megafossils and microfossils are relatively abundant, and they indicate a middle Niobrara age (Love, 1956a, p. 80).

BACON RIDGE SANDSTONE

Major outcrops of the Bacon Ridge Sandstone are present along both flanks of the Wolverine anticline, near the northern terminus of Big Game Ridge (pl. 1). Those on the east flank (fig. 5) extend north along the western slopes of Barlow Peak and Chicken Ridge to Channel Mountain, 1.5 miles southwest of the South Arm of Yellowstone Lake. Another outcrop of the formation is on the south end of the high ridge 15,000 feet southeast of the mouth of Red Creek.

A partial section of the Bacon Ridge Sandstone on Outlet Creek was described in connection with the Cody Shale. A complete section was measured on the north side of the Snake River about 5,000 feet southeast of the mouth of Sickle Creek, along the western base of Barlow Peak (measured by J. D. Love, Sept. 3, 1949):

	Thickness
Harebell Formation (part):	(feet)
8. Sandstone, siltstone, shale, and claystone, drab, soft	; con-
tains thin coal and bentonite beds; forms slope	200±

Contact between Harebell Formation and Bacon Ridge Sandstone.

Areal relations suggest that this is an unconformity and that at least 3,500 feet of Upper Cretaceous strata is missing here. (Compare with sections to the south in Jackson Hole.)

Bacon Ridge Sandstone:

- 7. Sandstone, light-gray, fine-grained, limy, massive in part, pepper-and-salt appearance; forms conspicuous bare cliff extending up from river level; is site of falls and potholes in river bottom; oyster shells, small pelecypods, and fossil mudcracks occur at several horizons....130

- 4. Sandstone, gray; weathers brown; remarkably evenly bedded, breaking into conspicuous slabs 6 in. to 2 ft thick; hard, limy; interbedded with softer shaly sandstone that contains numerous oysters and inocerami110
- 3. Sandstone, very light gray, massive, blocky; contains sparse small chert pebbles, oysters, and inocerami 40

Thickness (feet)

Bacon Ridge Sandstone—Continued

Total thickness of Bacon Ridge Sandstone......<u>520</u>

Contact between Bacon Ridge Sandstone and Cody Shale marked by sharp lithologic change from predominantly massive sandstone above to more silty shaly thin-bedded sandstone below.

Cody Shale part):

A section of part of the Bacon Ridge Sandstone on the high ridge 15,700 feet east-southeast of the mouth of Red Creek and 1,900 feet due west of hill 7669 is described as follows (measured by J. D. Love, Sept. 5, 1945):

Bacon Ridge Sandstone (part):

Thickness (feet)

- 3. Siltstone and shale, gray, fissile; contains pelecypods...... 10
 2. Shale, black, carbonaceous; interbedded with leaf-bearing

Total thickness of measured part of Bacon Ridge

mus at top......150

As can be seen by the outcrop widths, dips, and topographic expression (pl. 1), the computed thickness of the Bacon Ridge Sandstone varies considerably along strike, from less than 500 feet to more than 1,700 feet. The changes in thickness are believed to be the result of erosion that cut out the upper beds of the Bacon Ridge prior to deposition of the Harebell Formation.

The generally massive appearance of the sandstones, their blue-gray color caused by the flood of black grains, and the abundant fragments of thick (¼-½ in.) large *Inoceramus* shells with prismatic structure are characteristic of the Bacon Ridge Sandstone. Locally, thin coaly shale and coal beds are present. These become much thicker and more abundant in the upper part of the formation 6–8 miles south of Yellowstone National Park (Love, Hose, and others, 1951).

The Bacon Ridge Sandstone is richly fossiliferous in several places other than those already described. One of

the most fossiliferous localities is 3,000 feet east of the Snake River and 4,000 feet southeast of the junction of the Snake and Heart Rivers, west of the Wolverine anticline. Here a sandstone, 30 feet thick, with a bluish-gray appearance, contains masses of oysters and other large pelecypods. This sandstone is capped by I foot of carbonaceous shale that is overlain by I foot of gray and brown sandstone containing abundant small slender high-spired gastropods as well as pelecypods. These beds yielded (USGS Cat. No. 21500, identified by W. A. Cobban, written commun., Feb. 21, 1950):

Serpula sp.
Ostrea soleniscus Meek
Ostrea aff. O. subspatulata Forbes
Anomia micronema Meek
Anomia cf. A. gryphaeiformis Stanton
Brachydontes multilingera (Meek)
Protodonax magnus Vokes
Protodonax cf. P. cuneatus (Stanton)
"Corbula" undifera Meek var.
"Melania" aff. M. insculpta Meek

This and other collections of fossils from the Bacon Ridge Sandstone in southern Yellowstone National Park and farther south in Jackson Hole are all of middle Niobrara age (W. A. Cobban, written commun., 1950; Love, 1956a). The faunal types range from marine to brackish water, but the presence of coal beds and leaves indicates the temporary existence of a near-shore coal-swamp environment. These features, plus the thickness of sandstone, demonstrate that the shoreline oscillated or was at

near stillstand for a considerable length of time before the sea withdrew eastward into central Wyoming.

Fifty-five miles north of the southern Yellowstone National Park sections, Brown (1957) identified the Bacon Ridge Sandstone on Mount Everts and measured a section 525 feet thick (fig. 9). Fraser, Waldrop, and Hyden (1969) used a somewhat different classification. Fossils reported by them show that both the Telegraph Creek Formation and Eagle Sandstone are of Niobrara age and are therefore somewhat older than the units with those names in the Bighorn Basin, 70 miles to the east. Both lithologically and faunally these two formations in northern Yellowstone National Park closely resemble the strand deposits which characterize the Bacon Ridge Sandstone in the southern part of the park.

The regional extent of the intra-Cretaceous unconformity that bevels the Bacon Ridge Sandstone and crosses southern Yellowstone National Park is indicated in figures 9 and 16. The time of this uparching, discussed later, was Late but not latest Cretaceous.

HAREBELL FORMATION

The Harebell Formation is the most widespread and the thickest of all the sedimentary rock sequences in southern Yellowstone National Park. Broad exposures are present on the west flank of the Wolverine anticline, where the formation is 9,000 feet thick and forms the northwest end of Big Game Ridge (fig. 4). Other major exposures extend north from Big Game Ridge for 11 miles,

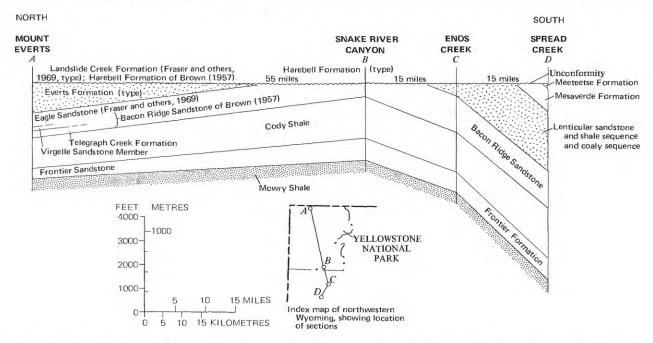


FIGURE 9. Diagrammatic cross section from northern Yellowstone National Park to Jackson Hole, showing relations of Upper Cretaceous named units to intra-Cretaceous unconformity. Stratigraphic section A is adapted from measured sections by Brown (1957) and Fraser, Waldrop, and Hyden (1969); B is from this report; C and D are from Love, Hose, Weitz, Duncan, and Bergquist (1951).

nearly to Yellowstone Lake. On Barlow Peak the lower 2,700 feet of the Harebell crops out (fig. 5), and on Chicken Ridge to the north, about 3,000 feet is present. All exposures of the Harebell terminate eastward at the Buffalo Fork thrust fault, along which Paleozoic rocks of the Washakie Range overrode this and older Cretaceous formations.

The Harebell Formation is a moderately soft sequence of tuffaceous gray, greenish-gray, and light-brown sandstone and siltstone and green and mustard-yellow to black siliceous bentonitic shale and claystone. Sparse thin carbonacous and coaly beds are present at several horizons. The formation was named from Harebell Creek which flows westward into the Snake River along the southern boundary of the park (Love, 1956b, p. 1900–1904). Inasmuch as the formation is discussed more fully in another publication (Love, 1973), only a summary is presented here.

The base of the type section is at the top of the Bacon Ridge Sandstone on the north side of the Snake River canyon, along the west lower slopes of Barlow Peak. The section continues southeastward for 2 miles along the north side of the canyon and then offsets to the south, crossing the southern boundary of the park at hill 10,065 (fig. 10), Mount Hancock quadrangle. Only the lower 2,700 feet of the type section (which is 6,200 ft thick) within the park is repeated in the present report (section measured by J. D. Love and J. L. Weitz, 1945 and 1966):

Harebell Formation (lower part of type section beginning at top of hill 10,065):

Thickness (feet)

47. Sandstone marker bed that bears a superficial resemblance to granite; light gray, very coarse grained, hard; weathers into highly distinctive light-gray angular blocks that form rock glaciers in places on the north face of Big Game Ridge; matrix is silty but less so than most sandstones in the Harebell Formation; many pebbles and cobbles of red, gray, black, brown, and white quartzite and other hard siliceous rocks as much as 4 in. in diameter, or possibly larger; unit has considerable lateral continuity in this area and was used for structural mapping; glaciers carried erratics of it up over Big Game Ridge and deposited them in boulder trains on the south

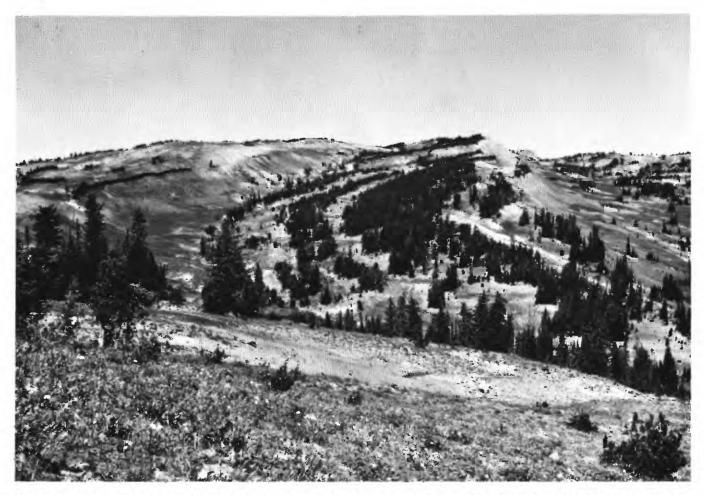


FIGURE 10.—View northwest along Big Game Ridge toward hill 10,065 on southern boundary of Yellowstone National Park, showing part of type section of Harebell Formation. Unit 47, a gray coarse-grained very hard marker sandstone, caps this hill and forms a dip slope with selective concentric tree distribution in center. Photograph by J. D. Love, Aug. 30, 1948.

	au	hickness	Thickness Thickness
Harel	oell Formation (lower part of type section beginning at top of hill 10,065)—Continued	(feet)	Harebell Formation (lower part of type section beginning (feet) at top of hill 10,065)—Continued
47.	Sandstone marker bed—Continued		
	side; thin section Wyo. 383 is typical lithology and con		23. Coal, black, impure
	tains abundant volcanic plagioclase and quartz withou		22. Shale, gray; has a few lenses of ledgy fine-grained sand-
	strain shadows; thickness is somewhat variable, with	ı	stone; 4-in. black to purplish-gray soft coaly clay shale
	maximum about	. 50±	in the middle of the unit is the site of a line of springs 50
46.	Tripartite ledge of sandstone at top and bottom and	i	21. Sandstone, light-gray; weathers olive drab; hard, fine
	quartzite pebble conglomerate in middle; unit form	s	grained, ledgy; some fragments of white tuff not in
	ledges at top of exposure, and continues southward a	s	place but close 5±
	dip slope about 4,000 ft; lenses of pink, gray, and black	ζ.	Offset for underlying beds, except for units 16-20, 10,000 feet north-
	quartzite pebbles as much as 4 in. in diameter; many	ÿ	east from bare northeast spur of Big Game Ridge at an elevation
	were fractured and recemented		of 9,700 feet, and 1,500 feet northeast of hill 10,065 to the upstream
45.	Sandstone, gray, medium- to coarse-grained, soft, car	-	end of the inner gorge of the Snake River canyon approximately
	bonaceous		1 mile downstream from the mouth of Crooked Creek. Units 16-20
44.	Shale; tan in lower part, middle 2 ft is black, and uppe		are described from southeast face of Barlow Peak, 8,000 feet north-
	part is gray and silty		west of Snake River canyon.
43	Sandstone, gray, hard and soft, ledgy; upper part of uni		20. Beds between Big Game Ridge and Snake River canyon
10.	is first ledge below top of exposure, ranges in thicknes		not sampled or described in detail; thickness determined
	from 15 to 20 ft, and lenses out one-fourth mile to		by subtracting thicknesses of units 16–19 from computed
	the east		interval between top of unit 15 and base of unit 21;
49	Sandstone, gray, hard and soft, ledgy		entire sequence exposed on southwest side of Barlow
41.	Sandstone, gray, hard and soft, ledgy, medium-grained		Peak, but only the upper part is exposed on Big Game
40	thin-bedded; contains carbonaceous flecks		Ridge north of unit 21; sequence is drab sandstone and
40.	Largely covered; apparently underlain by soft sandstone		lesser amounts of drab to dark-gray siltstone, shale, and
	and siltstone in about 10-ft units		claystone; no conglomerate observed700±
39.	Largely covered; puffy brown to gray bentonitic shale		19. Sandstone, brown, medium- to fine-grained, very silty;
	forms rounded ridge in lower 20 ft; at top is very fine		in hard and soft coarsely bedded to massive layers 130
	grained gray ledge-forming sandstone that contains		18. Shale, claystone, and siltstone, bluish- to greenish-gray,
	carbonaceous debris with carbonaceous shale below and		blocky in part30
	olive-drab clay shale above	. 63	17. Sandstone, gray, clean to silty, fine-grained, slabby to
38.	Claystone, gray, and plastic coaly shale	. 5	massive; with pepper-and-salt appearance because of
37.	Sandstone, gray to olive-drab; forms small ledge; lense	S	abundance of black grains; forms conspicuous ledge 10
	out 30 ft east of line of section; yielded pollen of lates	t	l6. Sandstone, siltstone, shale, and claystone, dull greenish-
	Cretaceous age (colln. D3877-C; R. H. Tschudy, writter	1	gray; monotonous sequence of interbedded lithologies;
	commun., Feb. 10, 1967)	. 1	forms slope interrupted by weak ledges500±
36.	Covered interval across swale to lowest outcrop on main		Underlying units described from Snake River canyon.
	spur to south		15. Upper of two marker sandstones in basal part of forma-
35.	Sandstone, gray, hard; forms western summit of prom		tion, gray to brown; massive in part; has minor clay-
	inent knob		stone and siltstone breaks; makes cliffs at the upper
34.	Covered interval		part of the inner gorge of Snake River canyon, approx-
	Sandstone, gray; weathers brown; fine grained, thir		imately 8,000 ft southeast of the section on the south-
	bedded, slabby; forms weak ledge at eastern summi		west face of Barlow Peak; unit is silicified, hard, and
	of prominent knob north of big scar		coarsely blocky; weathers to angular fractured cliffs;
99	Covered interval; probably shale and siltstone		some beds at this locality are green, and much of unit
	Sandstone, gray; weathers brown; fine grained, thir		is a coarse-grained secondarily silicified grit that con-
31.	bedded, slabby; forms weak ledge		tains highly rounded pebbles of quartzite, dense hard
90			
	Covered interval; probably shale and siltstone		slate, and other siliceous rocks as much as 2 in. in
29.	Claystone, olive-drab; weathers to gray and tan; yielded		diameter but commonly less than one-half inch; thin
	conical dinosaur tooth of a theropod dinosaur of the		sections Wyo. 377, 378, and 379 are of representative
	Upper Cretaceous family Deinodontidae (probably a		types of sandstone and conglomerate; these show con-
	carnivorous dinosaur; identified by G. E. Lewis, written		siderable tuffaceous debris
	commun., Nov. 4, 1966)		14. Shale, drab
28.	Sandstone and siltstone, dull green; forms ledge; many		13. Sandstone, yellow, soft
	plant fragments on upper surface		12. Shale and sandstone, drab; in about equal amounts 20
	Shale, gray, hard, chippy in part		11. Sandstone, drab
26.	Shale, gray, with black to brown coaly shale at top	. 5	10. Sandstone and shale, drab; in about equal amounts 17
25.	Sandstone, light-olive; weathers to yellow rounded slopes	;	9. Sandstone, drab, shaly 7
	top 3 ft is ledgy crossbedded fine-grained sandstone	. 19	8. Shale, drab
24.	Claystone and shale, gray; sandy in part; rusty in basa	l	7. Lower marker sandstone, gray to brown, hard, cliff-
	3 in.; this basal bed yielded good pollen assemblage	•	forming; described and sampled where it makes lower
	of latest Cretaceous age (colln. D3877-A; R. H. Tschudy		part of inner gorge of Snake River canyon
	written commun., Feb. 10, 1967); 1 ft of coal 10 ft above		Offset 8,000 feet northwest from bottom of Snake River canyon to
	base; overlain by light-olive sandstone that weathers		southwest face of Barlow Peak on base of unit 7 for underlying
	to yellow rounded slopes		section.

Thickness (feet)

Offset from bottom of Snake River canyon to face of Barlow Peak—Continued

- 5. Bentonite, gray, with coaly partings...... 10
- 3. Sandstone, brown, massive to poorly bedded; pepper-and-salt appearance, fine grained; forms conspicuous ledge.... 10
- 2. Sandstone, siltstone, shale, and claystone, drab, soft; contains thin coal and bentonite beds; forms slope......200±

Contact between Harebell Formation and Bacon Ridge Sandstone. Areal relations indicate that this is an angular unconformity (fig. 9) and that, in comparison with the Spread Creek section (Love, Hose, and others, 1951), at least 3,500 feet of post-Bacon Ridge—pre-Harebell Upper Cretaceous strata is missing from the Snake River area.

Bacon Ridge Sandstone:

The remainder of the type section and other facies of the Harebell Formation are described in detail elsewhere (Love, 1973; Lindsey, 1972). The most conspicuous facies in areas south of the park is a vast flood of quartzite pebble to boulder conglomerate. The rock fragments are highly rounded and composed chiefly of red, green, black, white, and brown quartzite of Precambrian and possibly early Paleozoic age, derived from the Targhee uplift, 40 miles to the west in Idaho (Love and Reed, 1968, fig. 42). Lesser amounts of hard dense igneous rock, probably of Cretaceous age, deeply weathered Precambrian granite, and Paleozoic limestone and dolomite are also present.

The conglomerate facies thins rapidly northward from a maximum development of about 4,600 feet (the Bobcat Member, Love, 1973), 10 miles south of the park, to a few 50-foot conglomerate beds southwest of Mount Hancock along the park boundary. These thin and disappear still farther north. A few beds of conglomerate are present about 2,500 feet above the base of the 9,000-foot section northwest of Mount Hancock (fig. 4; Love, 1973, fig. 5), and sporadic quartzite pebbles occur as far north as the Snake River canyon (unit 15 in the type section). No conglomerates were observed (although thin ones could have

been missed) in the sections on Barlow Peak, Chicken Ridge, Overlook Mountain, and Channel Mountain.

As the conglomerates thin northward, the tuff content of the finer grained strata increases. Some of the claystone and siltstone zones weather on outcrop to puffy unvegetated bentonitic badlands that have surfaces which resemble popcorn. These tuffaceous beds, extensively glaciated, cropping out in areas of steep topography, and subjected to 40–50 inches of precipitation annually (Mundorff and others, 1964, pl. 2), are sites of major land-slides and smaller scale surficial creep. These phenomena reduce the accuracy of stratigraphic measurements in many places.

Volcanic debris, other than the bentonitic beds, consists chiefly of quartz bipyramids, volcanic plagioclase, and euhedral biotite (Lindsey, 1972). Magnetite is abundant in many sandstones.

In areas south of Yellowstone National Park, the Harebell is separated from the overlying Pinyon Conglomerate by an erosional or angular unconformity ranging up to 90° (Love, 1973). Everywhere in southern Yellowstone National Park, however, the top of the Harebell is either an erosional surface or is terminated by faulting. The Pinyon is present along the east and south sides of Mount Sheridan (following discussion), but in those areas it is in direct contact with Jurassic and Lower Cretaceous rocks. An estimated thickness of 15,000 feet or more of beds is present between the top of the Harebell and the Jurassic on Big Game Ridge, 6 miles southeast of Mount Sheridan (Love and Keefer, 1969a, p. D124). This indicates the great magnitude of the unconformity at the top of the Harebell in the southern part of the park.

Most of the Harebell Formation is nonmarine, as is indicated by abundant leaves and freshwater mollusks. Nevertheless, several fine-grained beds in various parts of the formation have yielded hystrichospheres and dinoflagellates that indicate some marine influence (Love, 1973), and one brackish-water *Mytilus* bed is present in the upper part of the formation 11 miles south of the park (Kauffman, 1973).

The conglomeratic part of the Harebell was deposited by eastward-flowing rivers that dumped the coarse clastic debris in a rapidly subsiding trough which, if we interpret the data correctly, extended northward from Jackson Hole across the central part of Yellowstone National Park. The depositional surface in this trough remained near sea level most of the time. Thus, when the youngest conglomerates were being laid down south of the park, the oldest were 10,000 feet below sea level (Love, 1973, fig. 16). A considerable amount of the volcanic debris apparently came from the north, as is indicated by its increasing abundance from south to north. Fraser, Waldrop, and Hyden (1969, p. 35) described andesite pebbles and cobbles in their Landslide Creek Formation (fig. 9)—sparse in the Mount Everts section, but much more abundant to the northwest.

The Harebell Formation is of Late but not latest Cretaceous age. This age assignment is based on collections of Cretaceous pollen, leaves, *Veryhachium*, dinoflagellates, dinosaurs, and chara (Love, 1973). Fossils of some kind are present in almost all sections. Leaves are abundant and well preserved in many sections. Claystones and siltstones throughout the region contain mollusks, but these are so fragile that they are commonly crushed and are unidentifiable.

The Harebell Formation probably correlates with part of the Lance Formation of the Wind River and Bighorn Basins. Brown (1957) identified the Harebell Formation on Mount Everts, 55 miles north of the type section (fig. 9), on the basis of the distinctive lithology and stratigraphic position. Later, these strata in the Mount Everts area were named the Landslide Creek Formation (Fraser and others, 1969, p. 34). Figure 9 shows our concept of the relations of these two sequences to each other and to older rocks; it seems likely that the Landslide Creek Formation is a northern extension of strata in the lower part of the type section of the Harebell Formation (Love, 1973).

CRETACEOUS AND TERTIARY SYSTEMS

PINYON CONGLOMERATE

Quartzite conglomerate beds assigned to the Pinyon Conglomerate occur in isolated exposures along the east and south sides of Mount Sheridan (frontispiece and fig. 11), in the northwest corner of the mapped area (pl. 1). (For detail of these outcrops, see Love and Keefer, 1969a, fig. 2.) The thickest section (Heart Lake Conglomerate discussion, measured section) consists of about 450 feet of green to rusty-brown conglomerate similar to that in the Harebell Formation and derived from the same Precambrian, and possibly lower Paleozoic, sources. Roundstones are commonly gray but some are black, red, tan, and blue green. A less abundant type of roundstone is tan and gray sandstone. Many of the hardest and densest quartzite fragments have a high polish. Fracturing and recementing is common, and most roundstones have conspicuous pressure scars. Bedding planes are poorly developed.

The entire sequence has been highly silicified by later introduction of silica, probably from adjacent igneous in-



FIGURE 11.—View north across Basin Creek toward Mount Sheridan and the type locality of the Heart Lake Conglomerate. Indicated are Huckleberry Ridge Tuff (Qhr), Heart Lake Conglomerate (QTh), Pinyon Conglomerate (TKp), Cloverly and Morrison(?) Formations (KJm), dike of rhyolite mixed with Pinyon Conglomerate (Qrd), and landslide debris (Qls). Photograph by J. D. Love, July 13, 1967.

trusions. Some silicification was so extensive that parts of the formation are barely recognizable as conglomerate (Love and Keefer, 1969a, fig. 5). Exposures are commonly in ragged cliffs and steep rubbly slopes.

The thickness is very erratic because of the irregular surface of deposition at the base and the extensive erosion of the top. The Pinyon here rests unconformably on strata in the Sundance and Cloverly and Morrison(?) Formations (fig. 11). As mentioned earlier, at least 15,000 feet of rocks was cut out beneath the unconformity between this locality and areas only 6 miles to the southeast. The Heart Lake Conglomerate of Pliocene or Pleistocene age (Love and Keefer, 1969a) unconformably overlies the Pinyon in some places, and younger rhyolite flows and welded tuffs overlie it in others.

No fossils were found in the Pinyon Conglomerate in southern Yellowstone National Park, and the sequence is correlated with the Pinyon on Pinyon Peak 5 miles south of the park boundary (fig. 1) on the basis of gross lithology and relations to older rocks. The Pinyon in its type locality is largely conglomerate which is virtually conformable with an underlying nonconglomeratic facies of the Harebell. Three miles farther southeast, however, on Gravel Peak, an angular unconformity of more than 90° is present between these two formations. At the north end of the Teton Range, the Pinyon laps onto rocks as old as the Madison Limestone (Love, 1973, fig. 24). In contrast, the unconformity at the base of the Harebell is apparent only in regional studies (Love, 1973, fig. 6); no local anomalies, such as 15,000 feet of erosion in 6 miles, for example, have been recognized at the base of the Harebell. Further, conglomerate beds in the Harebell disappear rapidly northward into Yellowstone National Park and no 400-foot conglomerates are known in the lower part of that formation in northern Jackson Hole (Love, 1973) or in sections on Barlow Peak or Chicken Ridge, 6 miles east of Mount Sheridan.

Until recently the Pinyon Conglomerate was thought to be entirely of Paleocene age on the basis of Paleocene mollusks and pollen at the base and Paleocene vertebrate fossils at the top (Love, 1956a; M. C. McKenna, unpub. data). All these fossils came from southern Jackson Hole, 30-40 miles south of Pinyon Peak. No fossils of any kind had been found on or near Pinyon Peak. Between these two areas is a 10-mile gap from which the Pinyon had been removed by erosion, and the conglomeratic strata had been correlated across this gap on the basis of lithologic similarity. During the summer of 1969, one tooth of Leptoceratops, a dinosaur of latest Cretaceous age, was found in place 150 feet above the base of the principal reference section of the Pinyon Conglomerate on Pinyon Peak (McKenna and Love, 1970). After reviewing all the available regional data, we concluded that the tooth was not reworked from older Cretaceous rocks and that the lower part of the Pinyon is of Cretaceous age. As is discussed

later, this indicates that the major tectonic activity which uplifted the Washakie Range and developed the Buffalo Fork thrust fault began in latest Cretaceous time rather than in Paleocene time.

TERTIARY SYSTEM

ABSAROKA VOLCANIC SUPERGROUP

The post-Pinyon Tertiary sedimentary rocks of southern Yellowstone National Park are predominatly of volcanic origin and are described in detail elsewhere (Smedes and Prostka, 1972). Therefore, the summary description of these sequences presented here is included only to provide a basis for discussion of tectonic events and geologic history. On the geologic map (pl. 1), these rocks are shown as the Absaroka Volcanic Supergroup. The geologic map of Yellowstone National Park (U.S. Geological Survey, 1972a) shows the following formations (in order from oldest to youngest) in or bounding the area of plate 1: Trout Peak Trachyandesite, Langford Formation, Two Ocean Formation, and Wiggins Formation.

TROUT PEAK TRACHYANDESITE

Whithin the mapped area (pl. 1), the Trout Peak Trachyandesite is present only in an upfaulted block along and north of Harebell Creek, west of the Harebell Creek patrol cabin and in a few exposures east of Grouse and Sickle Creeks. The rock is a massive sequence of trachyandesite and trachybasalt lava flows with minor amounts of interbedded volcaniclastic rocks (Smedes and Prostka, 1972, p. C25). The thickness is generally more than 200 feet. The sequence unconformably overlies Paleozoic and Mesozoic rocks and its potassium-argon age (48.0±1.3 m.y.) shows it to be middle Eocene (J. D. Obradovich, in Smedes and Prostka, 1972, p. C27).

LANGFORD FORMATION

The Langford Formation is present in two areas along the southern boundary of Yellowstone National Park. One area of exposures is north and northwest of the Fox Creek patrol cabin, and the other is west of the Harebell Creek patrol cabin. The formation consists of at least 200 feet of light-gray to brown water-laid volcaniclastic rocks, chiefly conglomerates of andesite and basalt fragments in a crystal and lithic tuff matrix. Petrified wood chips and log fragments are common in most exposures. A minor but conspicuous constituent east of Chicken Ridge is highly rounded quartzite boulder debris, probably derived from the Pinyon Conglomerate. Farther southwest, a 30-foot zone containing abundant quartzite roundstones, some as much as 8 inches in diameter, and Madison Limestone as well as volcanic rock fragments was observed at the base of the volcanic strata north of the Harebell Creek patrol cabin.

In several places, especially between Crooked Creek and the Fox Creek patrol cabin, boulders of granite and other Precambrian rocks 2–10 feet in diameter, as well as boulders of Paleozoic strata, are abundant. These must have been derived directly from the west flank of the Washakie Range, which stood high during this part of Eocene time, within 1–4 miles north and northeast of the Fox Creek patrol cabin. (See earlier discussion of Precambrian and pre-Devonian Paleozoic rocks.) Powerful streams carried both the volcanic and the nonvolcanic rock debris westward and southwestward from the Washakie Range.

No diagnostic fossils have been found in the Langford Formation. Its middle Eocene age (Smedes and Prostka, 1972) is based on its stratigraphic position above the dated Trout Peak Trachyandesite and below the dated Two Ocean Formation.

TWO OCEAN FORMATION

The Two Ocean Formation is present only as scattered outliers along the east margin of the map area (pl. 1) east of the Fox Creek patrol cabin. These outliers consist of about 150 feet of dark volcaniclastic strata that unconformably overlie the Madison Limestone. Most clasts are cobbles and boulders of andesite in a matrix of volcanic sand, silt, and ash. The formation is dated as middle Eocene on the basis of potassium-argon ages of 47.9±1.3 m.y. (sanidine) and 48.5±1.3 m.y. (biotite) by J. D. Obradovich (Smedes and Prostka, 1972, p. C29).

WIGGINS FORMATION

The Wiggins Formation, of Eocene age, is present north of the Fox Creek patrol cabin, east of the Buffalo Fork thrust fault. These strata originally buried even the higher ridges of Paleozoic rocks on the crest of the Washakie Range to a depth of perhaps 1,000–2,000 feet, but the ancestral mountain arch is now partially exhumed along the park boundary.

The lithology of the Wiggins Formation is similar to that of the Langford in that both are dominantly volcaniclastic and both consist chiefly of gray, red, and black andesite and basalt fragments. They differ in this area (but not in regions to the north and east) in that the Langford has abundant Paleozoic and Precambrian rock fragments, whereas the Wiggins does not. The matrix of the Wiggins ranges from pink to chalky white. Mudflows and debris flows containing giant basalt and andesite boulders are characteristic of the Wiggins but are less common in the Langford Formation in the mapped area.

The Wiggins was deposited on a surface of mountainous relief cut across rocks ranging in age from Precambrian to Eocene. Along and near the southern boundary of the park, the Langford and Two Ocean Formations were eroded away at several places prior to deposition of the Wiggins. The nearest possible source for the andesite and basalt boulders was vent areas east and northeast of the western margin of the Washakie Range.

The Wiggins Formation in its type area in the southern

part of the Absaroka Range had previously been thought to be of Oligocene(?) age on the basis of both lithology and fragmentary vertebrate fossils (Love, 1939). The discovery of a diagnostic Oligocene vertebrate fossil assemblage in white tuff beds and thin volcanic conglomerates resting on similar volcanic conglomerates in the lower part of the Wiggins Formation 3 miles south of Yellowstone National Park (Love, 1956a) was considered until recently to be confirmation of the Oligocene age of the formation. Newly acquired potassium-argon age determinations from the Wiggins, however, indicate that all of it is of Eocene age. These dated samples are from three localities-near Togwotee Pass, northwest of Wiggins Peak, and south of the original reference section on Steamboat Rock. East of Togwotee Pass, 33 miles south-southeast of the mapped area, Rohrer and Obradovich (1969) reported ages of 46.2±1.8 m.y and 46.5±2.3 m.y. on hornblende from the basal Wiggins. An airfall tuff about 800 feet above the base of the formation in the same area yielded potassiumargon ages of 44.4±1.4 m.y. (hornblende) and 45.5±1.3 m.y. (biotite) (J. D. Obradovich, quoted in Smedes and Prostka, 1972, p. C32). A sample from the highest horizon in the Wiggins Formation at the locality northwest of Wiggins Peak, about 50 miles southeast of the mapped area, yielded a potassium-argon age of 43.1 m.y. (J. D. Obradovich, written commun., 1972). Samples from ash beds 500-600 feet above the base of the Wiggins Formation 3 miles southwest of the original reference section and 53 miles southeast of the mapped area yielded ages of 47.1±1.3 m.y. and 46.7±1.5 m.y. (biotite) respectively, and biotite from a vitrophyre about 150 feet higher in the section gave an age of 44.6±1.2 m.y. (J. D. Obradovich, quoted in Smedes and Prostka, 1972, p. C32).

The discrepancy in ages between the potassium-argon dates and the vertebrate fossils prompted additional work on the fossiliferous strata. As a result, it is now known that the Oligocene strata lie in a channel cut into the Wiggins Formation and that the associated conglomerates are reworked Wiggins, rather than being tongues of the Wiggins.

The time boundary between middle and upper Eocene rocks that was established by Evernden and others (1964) is about 45 m.y. or slightly older, but the samples on which this conclusion is based are not correlated precisely with any extensive and diagnostic vertebrate fossil collections (M. C. McKenna, written commun., Dec. 29, 1971).

A large vertebrate fossil assemblage was recently obtained by M. C. McKenna and associates from the type section of the Tepee Trail Formation which underlies the Wiggins. In the vertebrate time scale, this fauna is (McKenna, 1972, p. 93): "later in age than any known Bridgerian assemblage. It would appear to be more primitive than the 'Uinta B' fauna, however. Possibly it is equivalent in age to the almost unknown 'Uinta A' fauna, but to

elaborate on that suggestion would first require more work in the Uinta Basin of Utah."

Lewis (1973) described a specimen of *Parahyus vagus* Marsh that was collected by Love (Aug. 8, 1936) from the type section of the Tepee Trail Formation. This taxon had previously been reported only from lower Eocene rocks. In Lewis' opinion (1973, p. 147, 149), the Tepee Trail specimen "casts doubt on the supposed age ranges of both *Parahyus* and the Tepee Trail."

Here again, there seems to be some discrepancy between the vertebrate time scale that makes the Tepee Trail probably late Eocene and the potassium-argon time scale that makes the lower part of the overlying Wiggins Formation late middle Eocene. This situation will doubtless be resolved by more fossil collections and more age determinations in the Yellowstone-Absaroka area.

TERTIARY OR QUATERNARY SYSTEM

HEART LAKE CONGLOMERATE

The Heart Lake Conglomerate is a unique sequence of conglomerate and lesser amounts of tuffaceous sandstone and claystone that crops out in two localities along the east and south slopes of Mount Sheridan (fig. 11), and also at one locality south of the canyon of Basin Creek (pl. 1). The type locality is 1.3 miles south-southeast of the lookout station on Mount Sheridan and has been presented elsewhere (Love and Keefer, 1969a). The total known outcrop belt is about 2½ miles long, and the thickness ranges from 75 to about 130 feet. The sequence is very susceptible to landsliding; hence, it crops out in conspicuous breakaway scars. These appear as chalky white cliffs at two of the localities.

Approximately 90 percent of the formation is conglomeratic, with angular to well-rounded pebbles, cobbles, and boulders as much as 3 feet in diameter (average size 2-4 in.) of Paleozoic limestone, sandstone, and chert, Tertiary volcanic rocks, and Precambrian quartzite embedded in a tuffaceous sandstone or claystone matrix. Another conspicuous and unique constituent is white to pale-green waxy talc, intermixed with chlorite, in both small pebbles and in the matrix of the conglomerate (fig. 12). Fragments of Mississippian Madison Limestone make up about 75 percent of the conglomerate beds; younger Paleozoic sandstones are somewhat less common. The Precambrian quartzite roundstones were almost certainly derived from the underlying and adjacent outcrops of Pinyon Conglomerate, whereas the Paleozoic rock fragments and the talc pebbles must have been eroded from ancestral highlands that existed a few miles to the west or northwest prior to the eruption of the main mass of rhyolite that caps Mount Sheridan.

The Heart Lake Conglomerate rests with angular unconformity on rocks ranging in age from Late Jurassic



FIGURE 12.—Detail of Heart Lake Conglomerate south of Basin Creek. Nearly all rock fragments are Madison Limestone. Matrix contains abundant tale, chlorite, and waxy very fine grained gray claystone.

to Paleocene and is overlain by the Yellowstone Group. In places the contact between the conglomerate and tuff appears to be transitional, with the tuffaceous matrix of the conglomerate grading upward into the overlying rhyolite welded tuff sequence, which is of Pleistocene age (Christiansen and Blank, 1972). This relationship, as well as the rhyolite content of the conglomerate, suggests that the deposition of the Heart Lake sequence could have immediately preceded or have been partly contemporaneous with the deposition of the Yellowstone Group. If so, the age of the conglomerate might be early Pleistocene. On the other hand, the rhyolitic debris might be related to that in the middle Pliocene¹ Teewinot Formation (Love, 1956a, b), 25-35 miles south of Yellowstone National Park, or perhaps to the early Pliocene, Camp Davis Formation (Love, 1956a), 60 miles south of the park. Both formations are dated by fossils, and one potassium-argon date of 9.2 m.y. was obtained from obsidian pebbles in the Teewinot Formation (Evernden and others, 1964, p. 185-186).

Many rounded fragments of rhyolite and obsidian that are too large and heavy to have been windborne from distant sources are present in several conglomeratic beds in the Teewinot Formation. No rhyolite vents with rock composition similar to that of the fragments in Pliocene strata have been found in Jackson Hole, so it is inferred that because of the position of the mountain barriers to the west, south, and east, the coarser debris had to come from vents in Yellowstone National Park to the north. This

¹The Miocene-Pliocene boundary is being actively debated. Various interpretations are summarized by the U.S. Geological Survey (1972c). If the boundary is as late as 5 million years, both the Teewinot and Camp Davis Formations would be of late Miocene age.

debris could have been carried southward by streams into Jackson Hole.

No fossils have been found in the Heart Lake Conglomerate. The data already discussed suggest only that the conglomerate could be as old as middle Pliocene or as young as Pleistocene.

DIKES

Igneous dikes were observed at nine localities in southern Yellowstone National Park; probably many additional ones were overlooked. No attempt was made to map or to describe these dikes in detail because all of them are inconspicuous and of limited extent. Nevertheless, they occur in a tectonically active belt between two major areas of volcanism, one to the north, east, and west in Yellowstone National Park and the other to the south, east of Jackson Lake.

Thin sections of rocks in most dikes were studied by R. S. Houston as a part of a regional investigation of Tertiary igneous and pyroclastic rocks in Wyoming (Houston, 1964). No age determinations have been made by anyone, and the dikes described below cannot be dated more closely than Tertiary or Quaternary because they do not cut any of the dated igneous or volcaniclastic rocks.

The following is a summary of data on the dikes:

- 1. Felsic dike, 2,000 feet northwest of milepost 14 on southern boundary of Yellowstone National Park; nearly vertical, strikes northwest; 15-20 feet thick; cuts Phosphoria Formation and related rocks; consists of pale-green to white perlite, opal, and granular rhyolite(?); highly fractured; some opal(?) parts fracture to cylinders; granular parts weather to chalky-white slabs that show flow lines; a very distinctive rock.
- 2. Mafic dikes crosscutting one another; 750 feet northnorthwest of milepost 16 on southern boundary of Yellowstone National Park; southwest dike dips east about 45° and has variable northwesterly strike; cuts Cloverly and Morrison(?) Formations; thin section Wyo. 374 of dark-greenish-gray dense porphyritic andesite is so highly altered to carbonate that the original rock type is uncertain.
- 3. Porphyritic andesite, 1,500 feet east-northeast of milepost 16 on southern boundary of Yellowstone National Park; nearly vertical, with strike N. 75° W.; cuts grayish-red claystone with limestone nodules in Cloverly and Morrison(?) Formations with no conspicuous contact metamorphism; rock is dark green, dense, hard; thin section Wyo. 352 contains altered plagioclase phenocrysts in a groundmass of plagioclase and magnetite and sparse biotite.
- 4. Dike, 5,000 feet northeast of milepost 16 on southern

- west-northwest; cuts Mowry Shale; rock is aphanitic, dull grayish green, with large phenocrysts of plagioclase and sparse biotite; thin section Wyo. 371 is so highly altered to carbonate that rock is difficult to classify; dike is possibly continuous with a similarappearing dike 2,000 feet east-southeast, but which is too small to show on map.
- 5. Dike, 11,000 feet southwest of Chicken triangulation station, on northeast side of Snake River canyon; vertical, with strike northwest; cuts Frontier Formation; dark-green dense hard slightly porphyritic basalt or andesite.
- 6. Dike, 5,000 feet southwest of Basin Creek Lake; 10 feet thick and strikes northwest; cuts Tensleep and Amsden Formations; consists of heavy dark-green to black rock with red grains and needle crystals; thin section Wyo. 355 is a pigeonite basalt.
- 7. Dike, 4,000 feet southeast of Basin Creek Lake; 10 feet thick; dip nearly vertical and strike east-west; cuts "Upper Sundance"; rock is black, hard, very fine grained, with tiny red crystals; thin section Wyo. 365 is a basalt containing abundant plagioclase and clinopyroxene and a lesser amount of magnetite.
- 8. Dike, 8,000 feet northwest of Basin Creek Lake (too small to show on pl. 1); faulted into segments that are en echelon; cuts "Lower Sundance" gray limy shale; rock is dark green, dense, and contains clusters of dark minerals; thin section Wyo. 373 is so highly altered to carbonate that rock is difficult to classify.
- 9. Dike, the west end of which is about 1,500 feet northeast of milepost 15; vertical, trends east-southeast; 30 feet wide near southeast end, 2-5 feet wide in west half; composed of dark-green dense basalt with some vugs filled with quartz crystals and zeolites(?); cuts red siltstone, sandstone, and claystone in Cloverly-Morrison(?) sequence.

QUATERNARY SYSTEM

YELLOWSTONE GROUP AND LEWIS CANYON RHYOLITE

A rhyolite lava-flow unit and two welded tuff sheets form the north and west borders of the map area (pl. 1). Isolated patches of welded tuff also cap hills and ridges within the sedimentary rock terrane; the most conspicuous is the cap on Mount Hancock. Christiansen and Blank (1972), who mapped the various welded tuff sequences throughout Yellowstone National Park, assigned those within our map area to the Yellowstone Group. The Yellowstone Group as defined by them is considerably modified from the original definition of the Yellowstone Tuff of Boyd (1961, p. 393-400). Three major ash-flow formations representing different episodes of volcanism have been recognized. Two of these, the Huckleberry Ridge Tuff at the base and the overlying Lava Creek Tuff, are boundary of Yellowstone National Park; strikes shown on plate 1 and are pertinent to our interpretation

of tectonic events and discussion of geologic history because they were involved in extensive crustal movements.

The following generalized descriptions of the two rhyolitic tuff sequences and the rhyolite flows between them are from studies by Christiansen and Blank (1972): Lava Creek Tuff: Consists chiefly of as much as 500 feet of ash-flow tuff which is largely densely welded, gray where fresh, brown on weathered surfaces; generally contains 30–35 percent phenocrysts, mainly quartz, alkali feldspar, and plagioclase but has a basal zone in which phenocrysts are very sparse.

Lewis Canyon Rhyolite, which underlies the Lava Creek Tuff, consists of a series of lava flows that has a combined thickness of as much as 600 feet; these flows are gray and contain scattered large, deeply embayed phenocrysts, chiefly quartz, alkali feldspar, and plagioclase; unit forms ragged cliffs and bluffs along the north side of the Snake River, upstream from the South Entrance, and along both sides of Heart River.

Major erosional, and in places angular, unconformity. Huckleberry Ridge Tuff: A compound cooling unit of rhyolite ash-flow tuff, with a maximum thickness of as much as 900 feet; largely densely welded, gray where fresh, brown on weathered surfaces; most of unit contains about 20–25 percent phenocrysts, mainly quartz, alkali feldspar, and plagioclase, but certain zones are characterized by only about 10 percent phenocrysts; locally contains rhyolite lava flows and breccias in the Mount Sheridan area.

Potassium-argon age determinations show that the Huckleberry Ridge Tuff is about 2 m.y. old and the Lava Creek Tuff about 600,000 years old. R. L. Christiansen (oral commun., 1971) considered the Huckleberry Ridge Tuff to be equivalent to the most widespread welded tuff unit in the type section of the Bivouac Formation (Love, 1956b, p. 1911-1913) in Jackson Hole, 20 miles south of Yellowstone National Park. The basal part of this tuff has a potassium-argon age of 2.5 m.y. (Love and Reed, 1968, p. 101). The reason for the discrepancy in age between the Huckleberry Ridge Tuff and the tuff in the Bivouac Formation has not been determined. About 135 feet above the base of the Huckleberry Ridge Tuff south of Mount Sheridan is a 20-foot bed of white hard laminated slightly carbonaceous water-laid strata that yielded a nondiagnostic pollen assemblage (Love and Keefer, 1969a, p. D129).

LANDSLIDE AND GLACIAL DEPOSITS

Extensive surficial deposits, exhibiting characteristics of both landslide and glacial origin, occur along the floors and slopes of many valleys, particularly in the west half of the mapped area (pl. 1). No attempt was made to differentiate and classify these deposits; they have been studied in detail by G. M. Richmond, K. L. Pierce, H. A. Waldrop, and others (U.S. Geological Survey, 1972b).

The combination of high relief, steep valley walls, and

soft plastic character of most of the Mesozoic sedimentary sequences is particularly favorable for large-scale mass wasting. The landslides are generally in the form of slumps and small mudflows. In many places the amount of valleyward movement of individual masses is slight, but sufficient to warp the ground surfaces and produce irregular ridges that locally impound water in small ponds. The landslides along the east slope of Mount Sheridan are predominantly talus accumulations.

Coarse bouldery debris along some ridges and slopes and mantling parts of valley floors is of glacial origin. The deposits represent remnants of ground and lateral moraines; no well-defined end moraines were observed. Regional data indicate that the entire area was overridden by ice during one or more glacial episodes (Love, 1961, p. 1750-1754; Richmond and Pierce, 1971). Oversteepening of valley sides by ice carving, followed by saturation of steep slopes of bedrock, such as those in the Harebell Formation, and by glacial melt waters as the ice retreated undoubtedly contributed significantly to the development of landslides throughout the area. In addition, the large-scale faulting and nearby volcanism during Quaternary time must have been accompanied by many severe earthquake shocks. These would have tended to increase the size and activity of the unstable areas and would have prevented them from becoming stabilized.

HOT SPRINGS DEPOSITS AND ASSOCIATED HOT SPRINGS

Several small areas of hot spring deposits occur along or near the Snake River within Yellowstone National Park. A large area of similar deposits in the Heart Lake Geyser Basin, northwest of Heart Lake, was described in some detail, and maps, drawings, and the history of discovery were presented by Peale (in Hayden, 1883, p. 289–299). His descriptions are not repeated here.

The South Entrance Hot Springs are so designated here in order to avoid confusion with the Snake River Hot Springs farther upstream. Some confusion in the past was caused by Allen and Day (1935, p. 333-336) naming the springs near the South Entrance the "Snake River Springs." They were mentioned briefly by Peale (in Hayden, 1883, p. 300-301), who gave water temperatures as ranging from 180° to 150°F. They were not mentioned by Hague and others (1899) and are not named on the Huckleberry Mountain topographic map. The hot springs extend from the southern boundary of the park northward for about one-half mile in a roughly elliptical area. Many small orifices emerge from alluvium and others from the Amsden Formation and Tensleep Sandstone. No detailed map of the vents has been made and only a few measurements of flows of water. Most springs are warm but, as noted by Peale, a few small vents emit almost boiling water. Allen and Day (1935, p. 333–336) gave two water analyses, rates of flow, temperatures, and geographic data on several clusters of springs. They considered the water to be alkaline, with an estimated combined flow from all vents of 0.461 second feet (about 300,000 gallons per day) of water with temperatures ranging from 51° to 72.8°C. Some travertine is present, as well as siliceous sinter cones and sinter-capped terraces. It is not known if the thermal activity is static, increasing, or declining.

Four miles farther up the Snake River from the South Entrance Hot Springs are the Snake River Hot Springs. These were named by Hague (in Hague and others, 1899, p. 177–178), were renamed Chalk Springs by Allen and Day (1935, p. 388) but are shown on the Huckleberry Mountain quadrangle, 1956, as Snake Hot Springs. They should not be confused with the "Snake River Springs" of Allen and Day, which in the present report are called the South Entrance Hot Springs. The Snake River Hot Springs comprise two groups of very different springs, 1,800 feet apart. Both were discussed briefly by Hague (in Hague, and others, 1899, p. 177–178 and pl. 24). Allen and Day described and rephotographed the eastern group (their Chalk Springs) but did not mention the western group which is by far the largest.

Springs in both groups emerge through or are adjacent to gently dipping Madison Limestone (Mississippian) but

only the eastern group has deposited travertine. No chemical analyses are available for any of the springs. Some orifices in both groups emit boiling water. The combined flow from the eastern group was estimated by Allen and Day (1935, p. 391) as about 0.1 second feet (approximately 65,000 gallons per day). The western group, however, has a tremendous discharge of hot sulfurous water from two vents, both of which emerge from an alluvial flat adjacent to the Madison Limestone.

The southern of these large springs (fig. 13) flows an estimated 6 million gallons per day and the northern one, 100 feet to the north, flows about 2 million gallons per day, for a combined total of about 8 million gallons per day. The water in both springs is boiling, but the southern spring apparently emits superheated water. Thousands of tiny gas bubbles explode with a sharp crackling noise, like popcorn in an overheated pan, as they reach the water surface. Gas in the northern springs emerges in large bubbles that break with the conventional "blurps."

About 100 feet south of the southern spring is a coldwater spring that flows an estimated 75,000 gallons of water per day. This stream merges with the streams from the hot springs and creates a hot creek. Observations



FIGURE 13.—Largest hot spring in western group of Snake River Hot Springs, flowing an estimated 6 million gallons per day of clear, slightly sulfurous water that appears to be superheated. The "grainy" appearance of the water in places is caused by myriads of tiny gas bubbles that explode with a crackling noise like pop-

corn in a hot pan, as they reach the surface. The springs emerge from an alluvial flat composed of postglacial silt that must have been deposited before the springs emerged. Note white leg bone of large mammal projecting from silt bank at upper left. Photograph by J. D. Love, Aug. 1, 1972.

during a period of several years indicate that the temperature of the creek fluctuates considerably, probably as a result of increased or decreased flow of the cold spring.

The large hot springs are younger than the alluvial surface through which they emerge. Mammal bones project out from silt and clay forming the vertical sides of the largest orifice at a depth of 4 feet below the present land surface (fig. 13). Adjacent geomorphic data suggest that this alluvium is only a few thousand years old (a carbon-14 sample of shell material from below the terrace surface at the eastern group of hot springs has been submitted for analysis) so it seem likely that the big springs are Holocene. There is no evidence that the big springs, at least, are declining in vigor.

The eastern group of the Snake River Hot Springs (Chalk Springs of Allen and Day) deposited a considerable amount of travertine along the south side of the Snake River. Two conspicuous vents, one 10 feet across the other 15 feet, surrounded by deposits of white travertine, have been cut into and extinguished by the Snake River (fig. 14). It is interesting to compare the photograph taken in 1949 with that taken 23 years later and also with older

photographs by Hague and others (1899, pl. 24) and Allen and Day (1935). The amount of erosion of travertine and changes in orifices in about 80 years can be observed. In addition, the description (Hague, and others, 1899, p. 177–178) of the features indicates that the hot spring activity then was substantially greater than at the present time. Between 1891 and 1949, the site of emergence of the hot springs moved upstream into the river bed where several small travertine cones were built. From some of these violently boiling water spouted continuously (fig. 14*A*) accompanied by hissing sounds. In 1972, however, these vents were no longer visible (fig. 14*B*).

The Basin Creek Hot Springs area is the site of a significant amount of calcareous hot spring deposits. The springs emerge from red porphyritic rhyolitic welded tuff 3,000–4,000 feet northwest of the junction of the Heart and Snake Rivers. As much as 20 feet of travertine is exposed in some places, but commonly only low mounds, terraces, or bare thin travertine crusts are visible. These deposits are intermittently exposed in a northwest-trending area about one-half mile long.

About one-half mile south of the Basin Creek Hot

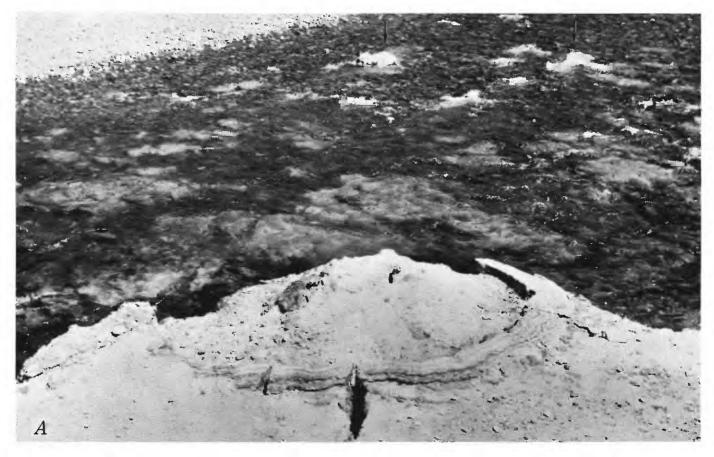


FIGURE 14.—View northeast, upstream along Snake River at Snake River Hot Springs (Chalk Springs of Allen and Day, 1935), Huckle-pl. 24—date of photograph not known) and Allen and Day (1935, figs. 147, 148—photograph taken in 1930). A, Extinct cone in the main river channel. Boiling water sprays almost constantly 2–3 feet high from some of the cones. Photograph by J. D. Photograph by J. D. Love, Aug. 1, 1972.

Springs, on the west bank of the Snake River, is a small area of travertine. The deposit is thin and distinctive only because the cooler parts of it are the sites of large elk "stomps," where the animals have pawed, chewed, or tramped out the travertine to a depth of about 1 foot below the level of the adjacent land surface. Boiling water flows from the travertine area at a rate estimated as about 50,000 gallons per day. Rhyolite welded tuff is on the west and southeast sides of the main vents.

Another small area of travertine is on the north face of Huckleberry Ridge, in the bottom of a steep ravine, 7,000 feet almost due north of milepost 16 on the southern boundary of Yellowstone National Park. No thermal activity occurs there at the present time. The extinct hot springs emerged from the Chugwater Formation near the northwest end of a small fault. The area of travertine is 100–200 feet in diameter and extends upward from the ravine bottom for about 30 feet. The travertine occurs as concentric arcuate shells of calcium carbonate.

ALLUVIUM AND TERRACE DEPOSITS

Quaternary faulting, on both large and small scale, has

decreased stream gradients nearly to the point of ponding in several areas, such as the upper courses of Grouse, Sickle, and Crooked Creeks and possibly the Snake River for several miles below the mouth of the Heart River. In these localities, stratified alluvial gravel, sand, and clay accumulated in significant amounts. In these nearly ponded areas, swampy meadows have developed and in wet seasons they are covered by a few inches of standing water. The alluvium in these meadows is chiefly dark clay that has a high organic content.

The Snake River valley from the mouth of Coulter Creek to the South Entrance is floored with deposits of unconsolidated gravel, sand, and silt. Some of these deposits are confined to the present-day river floodplain, but in a few localities, they underlie well-defined terraces that are as much as 40 feet above the river level. The terrace deposits, composed of gravel derived from conglomerates in the Pinyon and Harebell Formations to the south and of volcanic rocks to the north, generally support thick growths of grasses and other small plants and are the most convenient sites for access trails to this region.

About 5 miles northeast of the South Entrance and 1,000



berry Mountain quadrangle, Yellowstone National Park. For comparison with still older photographs, see Hague and others (1899, foreground has been partly destroyed by the river. Arrows indicate small spouting boiling springs emerging from travertine cones Love, July 23, 1949. B, Same view 23 years later, showing erosion of the cone and destruction of travertine cones in the river bed.

feet north of the Snake River Hot Springs on the alluvial flat is a small unnamed lake 300 feet across, with no inlet or outlet. This lake is of interest because its east margin is a completely submerged sheer cliff, the upper part of which is composed of consolidated gravel. The water level is almost at the terrace surface; maximum depth of the lake is not known, but a 75-foot plumb-bob did not touch bottom 3 feet out from the lake margin. The lake supports a healthy fish fauna, including cutthroat trout (Salmo clarki), commonly found in fast-moving streams. Presumably, the lake is in a sink hole that developed by collapse of a cavern in the underlying Madison Limestone after the alluvial flat was formed in postglacial time. The lake is apparently supplied and drained by an underground flow of freshwater (from the nearby Snake River) that is large enough to keep the fish fauna flourishing in both winter and summer.

ROCKS OUTSIDE MAPPED AREA THAT ARE PERTINENT TO TECTONIC HISTORY

UPPER EOCENE INTRUSIVES

Several major igneous intrusive bodies cut the Wiggins Formation in the Yellowstone-Absaroka region. Three of these have been dated. The Birch Hills, a dacite intrusion 10 miles west of the mapped area, has been dated by fission-track method as 40.5±2.6 m.y. on apatite (L. L. Love, 1972). The Washakie Needles, a dacite body which cuts through the Wiggins Formation 60 miles southeast of the mapped area, has been dated by fission-track method as 38.8±1.6 m.y. on sphene (L. L. Love, 1972). A quartz monzonite dike that intruded the Wiggins Formation near Kirwin, 50 miles east-southeast of the mapped area, has a potassium-argon age on biotite of 40.2±1.4 m.y. (Schassberger, 1972).

OLIGOCENE WHITE RIVER FORMATION

As mentioned previously, 3 miles directly south of milepost 29 on the southern boundary of the park, a diagnostic Oligocene vertebrate fossil assemblage was found (Love, 1952; 1956a; McKenna, 1972, p. 94-96). This occurrence of about 100 feet of chalky white tuff and claystone interbedded with lesser amounts of volcanic conglomerate is significant because it is the only known record of what may have been happening in Yellowstone National Park during Oligocene time. A similar lithologic sequence several hundred feet thick and likewise containing Oligocene vertebrate fossils is present to the northwest, diagonally across Yellowstone National Park, 35 miles west of the northwest corner of the park, on top of the Centennial Range (Mann, 1954, p. 43). These two occurrences, both on the crests of Laramide mountain ranges, suggest that during Oligocene time there was deposition of air-fall ashes, perhaps in part from distant sources, associated

with locally derived conglomeratic debris reworked by streams that drained a mountainous topography.

MIOCENE COLTER FORMATION

No Miocene sedimentary rocks have been recognized in Yellowstone National Park, but they are present 3 miles south of milepost 29 along the southern boundary of the park, in the same area as the White River Formation just described. They are considered to be part of the Colter Formation (Love, 1956b), are about 1,000 feet thick, crop out for a distance of about 1 mile, and contain vertebrate fossils of early Miocene age (McKenna, 1972, p. 96–97). A brief discussion of the Colter is presented here because the formation almost certainly originally extended into the park. The downfaulted erosion remnants still preserved to the south are involved in several tectonic events that affected southern Yellowstone National Park and, hence, give a maximum age for these events. In addition, the lithology and fossils of the Colter Formation supply data on the type of Miocene volcanism and local environmental conditions in the area.

The Colter Formation consists almost entirely of gray fine- to coarse-grained poorly lithified crossbedded to massive volcanic sandstone. The sand grains are angular and intermixed with abundant glass shards, but no beds of vitric tuff or pumicite were noted. A few thin lenses of andesite and basalt pebble conglomerate are present. Claystones are extremely sparse. Because of badly slumped and extensively glaciated exposures, details of the contact between the Colter and underlying vertebrate-bearing Oligocene rocks are somewhat obscured; however, the available data indicate that there is an erosional, and possibly an angular unconformity between them. No younger sedimentary rocks overlie the Colter in the Emerald Lake area, 4 miles south of the park boundary.

STRUCTURAL GEOLOGY

Sedimentary rocks in south-central Yellowstone National Park are strongly deformed into large north- and northwest-trending folds and fault blocks (pl. 1). These structures, which were developed during both Laramide (Late Cretaceous-early Tertiary) and later deformations, are grouped into four major tectonic subdivisions. These are, from east to west: (1) The Washakie Range, with Buffalo Fork thrust fault bounding it on the west; (2) the Wolverine and Hancock anticlines; (3) a normal fault complex along the southeast and east margins of the Basin Creek uplift; and (4) the Basin Creek uplift. A fifth major tectonic feature, west of the area of this study, extends northward into the southwestern part of Yellowstone National Park. This feature is an uplift constituting the northern prong of the Teton Range (Love, Reed, and others, 1973), which is separated from the Basin Creek uplift by a syncline with Upper Cretaceous and Paleocene rocks along the trough line.

WASHAKIE RANGE AND BUFFALO FORK THRUST FAULT

The Washakie Range (figs. 1, 3) comprises a chain of mountainous uplifts that forms the northwestern margin of the Wind River basin in central Wyoming, and extends northwest for a distance of about 85 miles into northwestern Wyoming (Love, 1939; Bengtson, 1956; Love and Keefer, 1969a, fig. 1). The range was uplifted, thrust westward and southwestward (Love, 1973, pl. 1), and deeply eroded during Laramide deformation, then was buried by the thick pile of Eocene volcanic rocks of the Absaroka Range. Some of the structural features have now been exhumed along major stream drainages; the narrow belt of Paleozoic and lower Mesozoic strata along the east side of the present area of study (pl. 1) represents the northernmost exposures of the Washakie Range in northwestern Wyoming.

Within the mapped area, the structure of the exposed segment of the Washakie Range is in the form of a single, north-trending, sharply folded anticline, with a gently dipping east flank (12°–20°) and a steeply dipping to overturned west flank. The fold developed along the crest of the westward-moving Buffalo Fork thrust block (fig. 15) and is part of a more extensive uplift that remains buried beneath the Absaroka Volcanic Supergroup to the east and southeast. Strata of the Devonian Darby Formation are the oldest rocks exposed, but the presence of large (as much as

10 ft) boulders of Precambrian crystallines and soft schists and gneisses in the basal part of the volcanic sequence in this area indicates that nearby parts of the uplifted block had been eroded to the basement complex before Absaroka volcanism began. The Precambrian core of the Washakie Range is exposed in some structural features approximately 15 miles south of the southeast corner of the mapped area (Love, 1956d).

The steep west flank of the Washakie Range is broken by a major thrust fault. In some previous reports (Love, Keefer, and others, 1951, fig. 6; Bengtson, 1956, p. 161) this feature was referred to as the Barlow thrust (named from Barlow Peak shown on pl. 1), but later work (Love, 1956c, pl. 1) showed it to be continuous with the Buffalo Fork thrust fault that is exposed along the west edge of the Washakie Range for a distance of about 25 miles southeast of the park boundary.

The Buffalo Fork thrust fault divides steeply westward dipping to overturned Paleozoic and Triassic rocks on the east from moderately gently eastward dipping to overturned Upper Cretaceous strata on the west; maximum stratigraphic displacement may be 10,000 feet. The dip of the fault plane is probably about 30° ; the plane is nowhere exposed within the park, but 6 miles to the south, in Mink Creek Canyon, it dips 25° . As is indicated on cross sections A-A', B-B', and C-C' (pl. 1) and in figure 15, the trace of the Buffalo Fork thrust shown on the geologic map (pl. 1) is virtually coincident with that of a late Cenozoic normal fault along which the overriding plate of the thrust is believed to have been dropped about 2,000 feet.

The above interpretation is based on a study of present

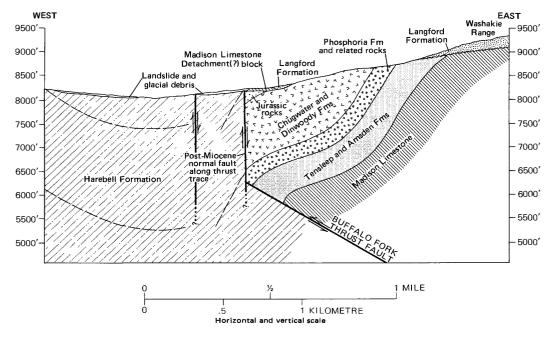


FIGURE 15.—East-west interpretive structure section through detachment(?) block of Madison Limestone, showing relation to Washakie Range, Buffalo Fork thrust fault, and post-Miocene normal fault along the thrust trace. Line of section shown on plate 1.

elevations of outcrops and on the boulder trains of Paleozoic and Precambrian rocks derived from the Washakie Range and incorporated in the Langford Formation. One of the key localities is in outcrops of the latter formation on Pinyon Peak (6 miles southwest of milepost 28 on the southern boundary of the park) where, at an elevation of 9,500 feet, boulders of Paleozoic rocks as much as 17 by 10 by 6 feet, as well as Precambrian granite, are present. These could only have originated in the Washakie Range (the closest other source is the Teton Range, 20 miles to the west), from which they were transported downhill to Pinyon Peak. As previously discussed, the nearest possible exposure of Precambrian rocks during Langford time is thought to have been 2-3 miles north of the Fox Creek patrol cabin and 9 miles northeast of Pinyon Peak, in an area now concealed by the post-Langford Wiggins Formation. The present elevation of this postulated source area is probably somewhat less than 9,000 feet. Assuming, conservatively, a gradient of 50 feet per mile for the surface over which the boulders were transported, the postulated source area must originally have been at least 500 feet higher than Pinyon Peak at the time of boulder deposition (about 1,000 feet higher than today). Other control points provide additional information. For example, 4 miles east of the Pinyon Peak, on the east side of the normal fault, the downfaulted base of the Wiggins (the Langford is missing) is presently at an elevation of 7,800 feet, 1,700 feet lower than the Langford exposures on Pinyon Peak. At this locality there are almost no Paleozoic and Precambrian boulders.

On the basis of the available data, we find it logical to conclude that during Eocene time the Precambrian and Paleozoic rocks of the Washakie Range stood at least 1,000 (and perhaps 2,000) feet above the locally derived debris to the west and that the present subdued configuration of the exhumed parts of the range is the result of both downfaulting and sagging in post-Miocene time. The time of major normal fault movement has not been determined precisely but it can be roughly bracketed between 2 and 15-20 m.y. This span is based on the fact that the Colter Formation of Miocene age is involved in downfaulting, but a gray tridymite-bearing pyroxene andesite porphyry (Hague and others, 1899, p. 199, 300), with a potassium-argon age of 2 m.y. (M. C. McKenna, written commun., 1970), came up along the already established normal fault.

Small amounts of movement apparently continued into Holocene time along parts of the normal fault. This is suggested by right-angle offsets of tributaries on the west side of Grouse Creek, the near ponding of Sickle Creek northeast of Barlow Peak, the undrained pass between Sickle and Crooked Creeks, the course of the northwest fork of Crooked Creek along the fault, the course of the main Crooked Creek for 1 mile below the forks, and the un-

drained valley east of the mouth of Crooked Creek. Similar types of evidence are present along the fault south of the park boundary.

About 2½ miles northwest of the Fox Creek patrol cabin is a small but significant outcrop of blue-gray coral-bearing Madison Limestone. It overlies Triassic red beds and is unconformably overlain by volcanic conglomerates in the Langford Formation. Figure 15 shows in cross section our interpretation of the relations of this limestone block to the Washakie Range, the Buffalo Fork thrust, and the younger normal fault. Most likely this outcrop is a detachment mass that slid westward downhill from the west flank of the Washakie Range during or prior to deposition of the Langford Formation in this area. At the time of emplacement the Washakie Range is thought to have been much higher than it is now and its west flank much steeper, and later normal faulting and sagging are thought to have reduced the slope to a comparatively low gradient (fig. 15). Both the Madison and the Langford in this locality are considerably brecciated by the later normal faulting.

One small east-trending normal fault juxtaposes Triassic strata on the north side against Permian and Pennsylvanian on the south side. Exposures are so limited that the eastern extent and the significance of the fault are unknown.

WOLVERINE-HANCOCK ANTICLINAL COMPLEX

The Wolverine-Hancock anticlinal complex, with surface expression entirely in Cretaceous rocks, dominates the structure in the central part of the mapped area (pl. 1; figs. 4, 5). The complex consists of two diverging anticlines, both of which plunge southeastward. The eastern one is the Hancock anticline, about 6 miles long; northward it merges with the Wolverine anticline and southward it broadens and dies out 1.5 miles beyond the park boundary. The western and much larger anticline is the Wolverine, which continues for at least 8 miles south of the park boundary. Originally, the name Hancock anticline included the north end of the complex (Love, Keefer, and others, 1951, fig. 6), but later work has shown that the Wolverine is the major feature, and the Hancock is subsidiary. Therefore, the name Wolverine is here extended to the north end of the complex. Between the two anticlines is a moderately shallow syncline that, in places, becomes sharp and locally is even overturned westward. One such occurrence is along the park boundary 2,000 feet west of hill 10,065.

Just before the crest of the anticlinal complex disappears northward beneath the rhyolites, it is especially well defined in exposures of the Cloverly and Morrison(?) Formations along the channel of the Snake River, 1.5–2 miles upstream from the mouth of Heart River (structure section *B–B'*, pl. 1). Chicken and Big Game Ridges, com-

posed of Upper Cretaceous rocks—chiefly the Bacon Ridge Sandstone and Harebell Formation (figs. 4, 5)—mark the east and west limbs, respectively; dips on the east flank range from 15° to 30° and those along the west flank range from 25° to 60°. The maximum amplitude of the fold complex may be more than 10,000 feet (structure section A–A', pl. 1), although the depths of the adjoining synclinal troughs cannot be accurately determined.

There is little surface evidence of the syncline that lies east of the anticlinal complex, for this major downwarp was almost completely overridden by the upper plate of the Buffalo Fork thrust fault. At the extreme southeast corner of the mapped area, however, a long narrow vertical to overturned wedge of Upper Cretaceous strata has been upfaulted. This wedge is bounded on the west by a normal fault and on the east by the thrust. Strata composing the northern end of this wedge, which extends for at least 6 miles south of the park boundary, are exposed in isolated outcrops along the west bank of the Snake River 0.5–1 mile north of the park boundary; these have lithology and marine fossils typical of the Bacon Ridge Sandstone.

West of this wedge is a structural feature believed to be a graben about 1 mile wide. This interpretation is based on two observations: (1) abnormally steep to overturned dips in quartzite-pebble-bearing strata in the Harebell Formation along the Snake River for about 1 mile upstream from the mouth of Crooked Creek; and (2) a ridge of rhyolitic tuff in the Yellowstone Group just outside Yellowstone National Park, 2,500 feet southwest of milepost 28. The tuff is light colored, almost white, and a thin section (Wyo. 381) shows it to be petrographically indentical to the Huckleberry Ridge Tuff on Mount Hancock (R. L. Christiansen, written commun., 1968). The tuff southwest of milepost 28 is the easternmost remnant of the Yellowstone Group that is now known in this region.

The base of the Huckleberry Ridge Tuff on the highest part of Mount Hancock is at an elevation of about 10,000 feet, and at the milepost-28 locality about 9,000 feet. Linear scouring by ice that left a blanket of glacial debris on all outcrops and extensive landsliding of incompetent beds in the Harebell Formation prevent accurate determination of the location and nature of the fault. If the Huckleberry Ridge Tuff at both localities was originally laid down at approximately the same elevation, the milepost-28 occurrence must have been downfaulted and possibly downwarped 1,000 feet in Pleistocene time. If, however, the tuff flowed along a valley cut through mountainous terrain, this milepost-28 occurrence may have been downwarped and downfaulted considerably less. Nevertheless, the suggestion is that the outcrop is at least 500 feet below its original position. The fault on the west side of the rhyolitic tuff outcrop is interpreted as continuing north through the distorted part of the Harebell and intersecting the major normal fault associated with the Buf-

falo Fork thrust northeast of the mouth of Crooked Creek (pl. 1).

Along the east side of Barlow Peak and Chicken Ridge the Upper Cretaceous strata all dip uniformly eastward. On the west side of the normal fault (along the Buffalo Fork thrust trace), west of Crooked Creek, 3½ miles north of the park boundary, is a small poor exposure of bentonite, porcellanite, and sandstone that looks more like the Frontier Formation than like the Harebell. These rocks are interpreted as having been dragged up along the trace of the Buffalo Fork thrust and then cut off when the later normal fault developed. Similar fault wedges, but of Jurassic rocks, occur along the fault plane 5 miles south of the park.

Except at the extreme northwest margin of Big Game Ridge, all the Upper Cretaceous strata along the west side of the ridge as far as the Snake River, dip westward. Because of thick forest cover and landsliding, however, it is difficult to obtain reliable structural data in this area, especially along the lower slopes. A south-plunging syncline in the Bacon Ridge Sandstone extends northward between the northwest base of Big Game Ridge and the Snake River channel. This syncline is parallel to the Heart River fault, an inferred Pleistocene normal fault directly to the west.

The northern part of the Wolverine anticline is buried beneath rhyolite tuff of the Yellowstone Group, and there is no reflection of the fold in these younger rocks. How far this large anticline may extend to the north or northwest is therefore not known. An isolated exposure of dark-gray to black thin-bedded shale and siltstone in the Cody Shale along the canyon cut by Heart River through the rhyolite welded tuffs, I mile north of the canyon mouth, strikes N. 5° E. and dips 21° E. This exposure could be interpreted either as part of the northeast flank of the Wolverine anticline or as part of the west flank of the adjacent syncline to the west. On the basis of projection of the anticlinal and synclinal trends, and especially the location and attitude of the Bacon Ridge Sandstone near the mouth of the Heart River, it seems more likely to us that the anticline swings to the north, east of the Heart River, and that this Cody Shale outcrop is on the west flank of the syncline (structure section C-C', pl. 1). Almost certainly the anticline has been offset or modified by prerhyolite normal faulting, evidence for which is given below.

NORMAL FAULT COMPLEX BETWEEN MOUNT SHERIDAN AND BIG GAME RIDGE

A normal fault complex involves Paleozoic, Mesozoic, and Cenozoic rocks in a southward-converging area about 3 miles wide between Mount Sheridan and Big Game Ridge (fig. 4). This is part of a sprawling network of normal faults of several ages that decreases in displace-

ment to the north and increases south of the park boundary (U.S. Geological Survey, 1968, p. 25-26). The fault with greatest displacement and most conspicuous effect on the topography and landscape is here named the Sheridan fault. It extends southward along the west edge of Heart Lake, at the eastern base of Mount Sheridan. At a point probably within 0.5-1 mile south of Sheridan Lake, it splits into two branches which diverge and follow slightly arcuate trends southward, then converge again near the south boundary of the park. The two branches are termed the "East Sheridan" and "West Sheridan" faults; they bound a lenticular strip with a maximum width of 2.5 miles of predominantly south-dipping Mesozoic rocks (Triassic to Upper Cretaceous) along the drainage divide between Red Creek and the upper valley of Basin Creek on the west and the Snake River and lower valley of Basin Creek on the east.

This area between the two branches of the Sheridan fault is important because the stratigraphic sequence is unusually complete, the structure is uncomplicated, and exposures are so good in landslide headwalls and on ridge tops that they are the sites for many of the measured sections previously described (pl. 1). No subsidiary faulting, such as is common west of the West Sheridan fault, was observed in this area.

The actual trace of the Sheridan fault complex is largely concealed by surficial deposits. The best evidence for the East Sheridan fault is found along the segment that extends northeast from the confluence of the Snake River and Coulter Creek (fig. 2) for about 2½ miles. In this interval the fault forms a nearly vertical contact between the Absaroka Volcanic Supergroup on the east and the Harebell Formation and Bacon Ridge Sandstone on the west. At the north end of this segment, the Huckleberry Ridge Tuff is in fault contact with the Cody Shale and Bacon Ridge Sandstone. The stratigraphic displacement (down on the east) on this segment of the East Sheridan fault may be about 8,000 feet (structure section A-A', pl. 1).

The East Sheridan fault continues northward beneath surficial deposits of the Snake River valley, then swings to the northwest, south of the Basin Creek Hot Springs, and continues on up the valley of Basin Creek. It is quite possible that the water in the hot springs comes up along a zone of fracturing associated with the fault. The rhyolites along the Snake River and north side of Basin Creek in this area are part of the Lava Creek Tuff that crops out at considerably higher elevations north of Mount Sheridan (Christiansen and Blank, 1972).

Along the north bank of Basin Creek, approximately 2 miles northwest of the mouth of the stream, intensely fractured and twisted Jurassic strata on the east are downfaulted against Triassic strata on the west. Although the stratigraphic displacement at this locality is only a few hundred feet, the fault here is believed to represent the

northwestern extension of the East Sheridan fault. It probably continues northward under landslide and glacial debris and intersects the main Sheridan fault south of Sheridan Lake.

The best direct evidence for the West Sheridan fault is at the southern boundary of the park, where the Bacon Ridge Sandstone on the east is in fault contact with Lower Cretaceous rocks on the west (pl. 1). The stratigraphic displacement here is nearly 5,000 feet. Farther north the fault trace is entirely concealed by surficial deposits, but field relations indicate that it must extend northward between the predominantly east-striking strata that crop out along the crest of the ridge east of Red Creek and the upper valley of Basin Creek and the north- and northwest-striking complexly faulted strata along the east edge of the Basin Creek uplift to the west (structure sections A-A', B-B', and C-C', pl. 1). The stratigraphic displacement diminishes northward and, 0.5-1 mile north of Basin Creek Lake, Triassic rocks are exposed on both sides of the inferred position of the fault. Still farther north, however, the amount of displacement increases along the main Sheridan fault.

Evidence that the main Sheridan fault zone continues northward along the east foot of Mount Sheridan is based on (1) the pronounced structural offsets in various mappable units of the Yellowstone Group; and (2) the precipitous face of Mount Sheridan, which appears to be a fault-line scarp. The Lava Creek Tuff along the east edge of the upper valley of Basin Creek, directly south of Heart Lake, occupies a large topographic and structural low that may have been formed in part by pre-Lava Creek faulting. Boyd (1961, pl. 1) recognized the fault on the east side of Mount Sheridan and extended it around the north margin of the mountain and on westward toward the south end of Lewis Lake (fig. 1).

Structure Section D-D' (pl. 1) shows the amount of warping and faulting that must have occurred in Quaternary time between Mount Hancock and Mount Sheridan. This movement, apparently occurring in several episodes, likewise is not everywhere obvious. For example, a normal fault, here called the Heart River fault, is postulated along the Heart River but in no place is it visible, and it does not offset the Lava Creek Tuff. This fault, along which the east block is downthrown, is presumed to diverge from the zone of weakness marked by the East Sheridan fault. Part of the evidence for the Heart River fault is the position and attitude of the Cretaceous outcrops along Heart River and the abrupt northward disappearance of the major Wolverine-Hancock uplift. Strong evidence is also furnished by the position of the Huckleberry Ridge Tuff east of Heart River, which, as is discussed later in the section on geologic history (phase 8), is 2,200 feet below that on Mount Hancock, 4 miles to the south-southeast, yet originally it must have been higher than Mount Hancock. It is therefore postulated that the northwest part of the Mount Hancock block was hinged down against the Heart River fault.

As can be seen on plate 1 and in figure 3, the Snake River follows a most peculiar course through the mapped area; this course is believed to have been influenced to a considerable extent by Quaternary tectonism. Some explanation is warranted to account for the river flowing northwest, in places opposite to the direction of major ice movement, out of a broad open flat area south of the Fox Creek patrol cabin, through a canyon 2,000 feet deep and 6 miles long between Big Game Ridge and Barlow Peak and Chicken Ridge (figs. 4, 5), then making a hairpin turn of more than 90° near the mouth of Heart River and flowing south along the trace of the East Sheridan fault. West of this turn no barrier is present to cause such a diversion; instead, there is the broad open valley of Basin Creek.

To account for the observed relations, we propose the following explanation. The original course of the Snake River in the area of the canyon was established at the time when the Washakie Range was 1,000-2,000 feet higher (discussed previously); the hairpin turn near the Snake River-Heart River confluence had not yet developed. West of this junction the river originally flowed westward along what is now the lower course of Basin Creek (but in the direction opposite to the present flow) and then turned southwestward, down the valley presently occupied by the lower course of Red Creek. The Red Creek segment may have been controlled by tectonism along part of the Basin Creek uplift, as well as by sagging and (or) downfaulting of the area northeast of the South Entrance (discussed later). Subsequent movement on the East Sheridan fault caused the hairpin diversion of the Snake River along its present southward course to the junction with Coulter Creek. From there, the river again turned at right angles and followed the northward-trending ancestral valley of Coulter Creek to the mouth of Red Creek. At this point it once more turned southwestward at right angles and rejoined its original valley that extended to the South Entrance.

BASIN CREEK UPLIFT

The Basin Creek uplift is a large arcuate area of Mesozoic and Paleozoic rocks (frontispiece) partly buried by rhyolite flows and tuffs along the west edge of the sedimentary rock terrane in southernmost Yellowstone National Park (Love and Keefer, 1969a). Only the eastern and southern margins of the uplift are exposed; the remainder is buried beneath rhyolitic rocks of the Yellowstone Group.

The Basin Creek uplift first began to rise as a broad gentle upwarp prior to deposition of the Harebell Formation and, as a result, several thousand feet of soft Upper Cretaceous rocks was eroded from the crest of the uplift. A pre-

Harebell outcrop map (fig. 16) shows the Bacon Ridge Sandstone and younger strata bending abruptly around the south and east sides of the ancestral uplift. When the outline of the post-Harebell Basin Creek uplift is superimposed on the ancestral one, it can be seen that they coincide on the south and east margins—the only ones where data are available.

Stratigraphic relations in the Mount Sheridan area, where the Pinyon Conglomerate rests directly on Jurassic and Lower Cretaceous rocks (fig. 11), indicate that the most intense folding of the Basin Creek uplift took place after deposition of the Harebell Formation, during Laramide deformation, probably at or near the end of Cretaceous time. The amount of Laramide uplift can be estimated within reasonable limits. As discussed earlier, the Harebell Formation, which has a maximum thickness of about 9,000 feet in Yellowstone National Park, was deposited at or near sea level in a subsiding basin. There is no evidence that the Basin Creek uplift contributed pre-Cody debris to the Harebell Formation, and so the major movement probably occurred after Harebell time. When it began, the base of the Harebell was more than 9,000 feet below sea level in the downwarp directly southeast of the uplift. By the beginning of deposition of the Pinyon Conglomerate, all the Harebell and an estimated 3,500 feet of pre-Harebell Mesozoic rocks as far down as Jurassic had been eroded from the crest of the uplift. Thus, the vertical movement in the southeastern part of the Basin Creek uplift during the most active phase of the Laramide orogeny was perhaps 12,500 feet. The uplift became elliptical, with a north-northwest trend and was at least 15-20 miles long and 15 miles wide.

Interpretations of the late Cenozoic geologic history of the uplift have been presented elsewhere (Love and Keefer, 1969a). To summarize, in late Cenozoic time, the uplift was rejuvenated and the Heart Lake Conglomerate was deposited by streams flowing eastward from the Paleozoic core exposed by this latest movement. Subsequently, the southeast margin of the uplift was cut by many large and small normal faults, commonly trending north or northwest, that have so disguised the configuration of the original uplift that it is difficult to reconstruct. The Laramide dips (toward the east) were reversed by faulting and tilting in many places. East fault blocks are commonly downthrown; amounts of displacement range from a few tens to many hundreds of feet. Thus, structural lowering of stratigraphic units is progressive from west to east across the area, with a maximum offset along the Sheridan fault complex at the east edge of the uplift. Cumulative displacement, including that along the Sheridan fault complex, may be as much as 16,000 feet (structure section A-A', pl. 1).

Christiansen and Blank (1972) described the development of a major caldera north of Mount Sheridan during

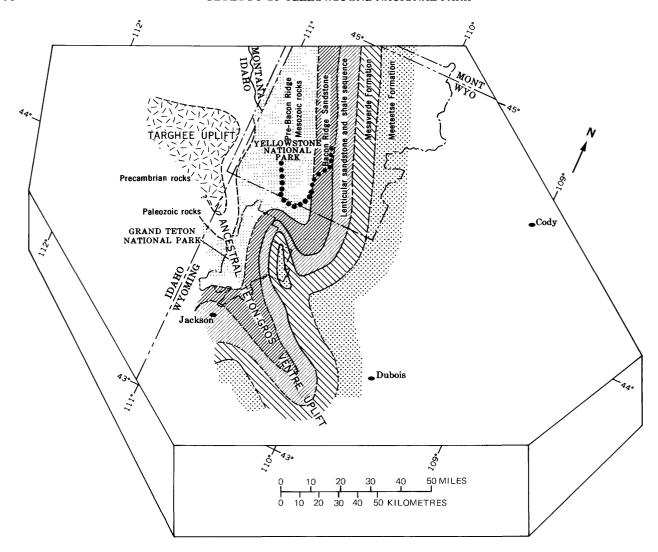


FIGURE 16.—Paleogeology at beginning of deposition of the Harebell Formation. Solid lines indicate adequate control; dashed lines are interpretive. Large dots outline site of post-Harebell Basin Creek uplift.

Pleistocene time; the steep northwest-facing slope of Factory Hill is believed to mark the south edge of the caldera. (For generalized outline of caldera, see Keefer, 1972, p. 22.) Rhyolite and tuff composing the Yellowstone Group emerged from this caldera and flowed south to and beyond the boundary of Yellowstone National Park. Rocks of the Yellowstone Group are offset by many normal faults; thus, it is reasonable to assume that a considerable amount of the small-scale faulting around the south and east margins of the Basin Creek uplift was caused by crustal shattering along the rim of this giant caldera. Some of the movement along the Sheridan fault and other faults that have major displacement is certainly related to the collapse of this caldera later in Pleistocene time. Nevertheless, displacement along several of the larger faults is less in the rhyolite than in the underlying sedimentary rocks. Where the displacement is less, it indicates that these faults existed prior to extrusion of the rhyolite from the caldera.

Faulting apparently continued into Holocene time in some places, for displacements of several talus accumulations were observed along the east slope of Mount Sheridan (R. L. Christiansen, oral commun., 1970).

POSSIBLE FAULTING NEAR THE SOUTH ENTRANCE

A topographic and stratigraphic anomaly that may have been caused by now-concealed faulting is demonstrated by the differential elevations of several outcrops of the Yellowstone Group along and near the southern boundary of Yellowstone National Park. For example, one area of the Huckleberry Ridge Tuff, 1 mile south of milepost 13 on the southern boundary of the park, is at an elevation of about 8,600 feet (Love, 1956d), yet to the north and northwest along the Snake River, the younger Lava Creek Tuff is at an elevation of 6,900 feet. This 1,700-foot difference in elevation, plus the straight course of the Snake River for 5

miles northeast of the South Entrance, suggests the presence of a major northeast-trending normal fault that dropped the north block down during post-Huckleberry Ridge pre-Lava Creek time, and it also suggests that this movement then governed the positioning of the younger tuff against the Påleozoic rocks on the upthrown (south) block (pl. 1). There is no way to determine how much of this discrepancy in elevation is the result of the tuffs having flowed out on rugged topography and how much is the result of faulting. The regional position and attitude of outcrops, however, suggest that at least half of the elevation discrepancy, and possibly more, can be attributed to faulting.

A small block of Madison Limestone along the Snake River flood plain is out of place with respect to the Madison outcrops to the south and is thought to be part of the downdropped block on the north side of the fault. The Paleozoic rocks high on the hills south of the Snake River are remnants of the south flank of the Basin Creek uplift.

LATE CRETACEOUS AND CENOZOIC GEOLOGIC HISTORY

The geologic history of the Teton-Jackson Hole area south of Yellowstone National Park has been discussed elsewhere (Love and Reed, 1968; Love, Reed, and others, 1973). The history during Late Cretaceous and Cenozoic times within and near the southern boundary of the park is summarized as follows:

1. Pre-Harebell Late Cretaceous

Accumulation of at least 4,000 feet or more of fluvial and coal-swamp deposits along eastward-flowing streams and on flood plains followed eastward retreat of the Niobrara sea. This deposition was interrupted by the rise of the broad gentle ancestral Basin Creek uplift in southern Yellowstone National Park. As a result of this movement, several thousand feet of soft Upper Cretaceous rocks was stripped off the top of the uplift.

2. Late but not latest Cretaceous

An elongate north-trending trough began to subside across the central part of the mapped area, and in it was deposited at least 9,000 feet of fine- to coarse-grained clastic debris that now constitutes the Harebell Formation. Sedimentary features and fossils indicate that deposition took place at or near sea level. Subsidence kept pace with deposition. The basin broadened and deepened south of the park. The most intense episode of arching of the Washakie Range and the Basin Creek uplift had not yet begun. The quartzite roundstones in the Harebell had their source in the Targhee uplift, a terrane of Precambrian metasedimentary rocks west of the southwest corner of Yellowstone National Park (Love, 1973). Volcanic debris from vents north or northwest of the park was carried in by wind and water.

3. Near end of Cretaceous

The Washakie Range was uplifted and thrust westward and southwestward over the east margin of the sedimentary downwarp in which the Harebell Formation had accumulated; the range was rapidly and deeply eroded, but the debris was carried out of the area. The Basin Creek uplift rose about 12,500 feet, at least in part, on the site of the ancestral uplift. Its new shape was probably that of a broad north- or northwest-trending elliptical arch whose crest lay a few miles west or northwest of the mapped area. The uplift was eroded to Jurassic rocks. The Wolverine-Hancock anticlinal complex rose out of the central part of the Cretaceous sedimentary trough and the soft strata in the upper part of the Harebell Formation on the crest of the fold were eroded away.

4. Latest Cretaceous and Paleocene

The Pinyon Conglomerate was deposited as a gigantic fan across and south of southern Yellowstone National Park. Parts of the fan rest on vertical to overturned and eroded edges of the Harebell Formation along the Buffalo Fork thrust fault south of the park boundary. On the Basin Creek uplift, the conglomerate overlies Jurassic rocks. The conglomerate source was the Targhee uplift to the west, as was that in the Harebell. The Cretaceous-Paleocene time boundary is somewhere within the Pinyon Conglomerate in this area and at the base of the sequence farther south in Jackson Hole (Love, 1973).

5. Eocene time

The part of the Washakie Range within Yellowstone National Park rose once again prior to, and during deposition of, the Langford Formation and then was eroded to the Precambrian core. Powerful rivers flowed west and southwest from the Washakie Range and spread fans that incorporated large boulders and slide masses of Precambrian and Paleozoic rocks, as well as volcanic debris.

During late or late middle Eocene time the Langford Formation was removed by erosion from part of the area along the southern boundary of Yellowstone National Park. This interval of erosion was followed by extensive volcanism on, and east of, the Washakie Range. Giant mudflows and debris flows that make up the Wiggins Formation extended west from the vent areas and buried the Washakie Range to a depth of several thousand feet. Large intrusive masses of dacite and quartz monzonite cut upward through the Wiggins Formation in late Eocene and possibly early Oligocene time.

6. Oligocene time

Before deposition of the White River Formation, 3 miles south of Yellowstone National Park, at least 1,000 feet of the Wiggins Formation was eroded away from the west margin of the Washakie Range. The fine-grained white ash of the White River contains remains of a varied assemblage of vertebrate fossils of early Oligocene age. Many of these are the same forms that lived contempo-

raneously on the plains of Nebraska and South Dakota. No record of events in Yellowstone National Park during Oligocene time has yet been documented.

7. Miocene time

About 1,000 feet of fine-grained tuffaceous sandstone composing the Colter Formation was deposited unconformably across the White River Formation and probably older rocks 3 miles south of Yellowstone National Park. The record of Miocene sedimentation and tectonic events within the park has been obliterated or concealed.

8. Pliocene and Pleistocene time

In central Jackson Hole, at least 6,000 feet of Pliocene lacustrine and fluviatile strata is present. Rhyolitic tuff is one of the major constituents, and the coarser beds contain rhyolite pebbles. No local source sufficient to provide such a large volume of this debris is known in Jackson Hole, and, so, vents in southern or central Yellowstone National Park are postulated. Just where they were located is not known

In late Pliocene or early Pleistocene time the Basin Creek uplift was once again raised, and its outline was probably more or less coincident with that formed during the Laramide episode of movement. This new rise triggered a flood of Paleozoic coarse clastic debris, chiefly limestone fragments (the Heart Lake Conglomerate). Boulders were carried by powerful streams eastward off the uplift and deposited in a fan along its margin. Abundant talc and chlorite fragments in the conglomerate suggest that dolomites on the uplift had been strongly metamorphosed, perhaps by nearby rhyolite intrusions. The dolomite source for talc is postulated because no Precambrian mafic rock fragments were observed. This, coupled with the pronounced silicification of Upper Jurassic and Lower Cretaceous sandstones and shales in the Mount Sheridan area, suggests strongly that the renewed arching of the Basin Creek uplift was more closely associated with igneous activity—perhaps doming above a magma chamber—than it was to conventional tectonism.

Christiansen and Blank (1972) and Keefer (1972) described the development 2 m.y. ago of an enormous caldera north of Mount Sheridan. It is possible that the rejuvenation of the Basin Creek uplift was related to the forces responsible for this caldera.

During late stages of deposition of the Heart Lake Conglomerate, some rhyolite volcanism—probably an early phase of the caldera development—occurred. Following this came the vast outpouring of the rhyolitic Huckleberry Ridge Tuff in the Yellowstone Group which spread across the mapped area from Mount Sheridan to Mount Hancock and for many miles on to the south and southwest. After an interval of erosion and faulting, younger rhyolite flows (the Lewis Canyon Rhyolite) and ash-flow tuffs of the Lava Creek Tuff were extruded in the downwarped and downfaulted areas of southern Yellowstone

National Park. This younger rhyolitic debris is of much more limited extent than the Huckleberry Ridge Tuff and occurs chiefly south of Heart Lake and along the Snake River downstream from the mouth of Red Creek.

At least four episodes of late Genozoic normal faulting have been recognized in the southern part of Yellowstone National Park. The oldest episode, possibly of Pliocene age, preceded the eruption of the Yellowstone Group. This is indicated by the fact that the stratigraphic displacements in the Upper Cretaceous strata and the Absaroka Volcanic Supergroup are substantially greater than the offsets in the rhyolite sequences. The second and third episodes of faulting took place in Pleistocene time—one after the eruption of the Huckleberry Ridge Tuff and the other after emplacement of the Lava Creek Tuff. The fourth episode is reflected locally in offset surficial deposits along the south and east slopes of Mount Sheridan and is of postglacial age.

The relative elevations of the Huckleberry Ridge Tuff on Mount Sheridan and on Mount Hancock are of significance from the standpoint of regional structural interpretation. Section D–D' (pl. 1) shows the present relations of the two outcrops of the tuff. The following discussion is an attempt to reconstruct the landscape and events affecting it, beginning at the time of the original outpouring of the Huckleberry Ridge Tuff. The tuff must have flowed out from the caldera north of Mount Sheridan onto a south-sloping surface that extended for more than 25 miles south of the park boundary. The interpretation of this regional southward slope is necessary in order to account for the location of known remnants of the Huckleberry Ridge Tuff in central Jackson Hole. The gradient of this slope can only be inferred, but it was probably very gentle.

The amount of topographic relief of the surface onto which the Huckleberry Ridge Tuff flowed is not known. Anomalous positions of local outcrops of tuff may be the result of differences in topographic relief, but these probably did not significantly affect the regional distribution of the tuff.

As a result of normal faulting and tilting of individual fault blocks, the Huckleberry Ridge Tuff shows major amounts of displacement. The most extreme example is demonstrated by the difference in elevation between the tuff on Mount Hancock at an elevation of 10,000 feet and the same sequence at 7,200 feet along the Snake River, 3.3 miles to the west. Outcrop data on Mount Hancock show the tuff to have a southwestward tilt of several degrees; 9° would be needed to account for the western outcrop being 2,800 feet lower. This tilting was probably related to downward hinging of the west flank of the Wolverine anticline against the East Sheridan fault.

Similarly, the Huckleberry Ridge Tuff east of the Heart River is at an elevation of 7,800 feet, as compared with 10,000 feet on Mount Hancock, 4 miles south-southeast.

Inasmuch as there are no known faults between these two sites, it is presumed that this 2,200-foot difference in elevation is the result of northward tilting of at least 7°, probably as a part of downward hinging of the Mount Hancock block against the Heart River fault. Originally, the Heart River site must have been higher than Mount Hancock, if, as we assume, the Huckleberry Ridge Tuff flowed southward downhill from the caldera.

The relative elevations of the Huckleberry Ridge Tuff have likewise been regionally reversed in other places. For example, at several localities on Mount Sheridan, the tuff is now 1,500 feet lower in elevation than that on Mount Hancock (8,500 ft versus 10,000 ft). The total structural displacement that has taken place between these two outcrop areas (disregarding details of local fault block displacements) during the post-Huckleberry Ridge time interval is, therefore, believed to be between 1,500 and 2,000 feet. The question of whether this offset was caused primarily by active uplift of the Mount Hancock block or, conversely, by active subsidence of the Mount Sheridan block, has a significant bearing on estimates regarding (1) the maximum local relief and elevation above sea level of the Basin Creek uplift during and after deposition of the Heart Lake Conglomerate, and (2) the magnitude of caldera subsidence of the central Yellowstone region during late Quaternary time.

The available evidence, though conjectural, suggests that the difference in elevation between correlative rhyolite units on Mount Sheridan and Mount Hancock resulted primarily from subsidence of the Mount Sheridan block. This interpretation is based on several lines of evidence. The pattern of normal faulting throughout the region is one of westward, northwestward, or southwestward tilting of individual fault blocks. This accounts for the west and southwest dips both in the Absaroka Volcanic Supergroup and in various units of the Yellowstone Group. For example, the west dips in the Absaroka volcanic rocks east of the Buffalo Fork thrust and associated normal faults are best explained by a downward rotation of the west margin of the block that lies east of the fault while the Mount Hancock block to the west remained relatively static. Such westward tilting of the eastern block could easily account for the total normal fault displacement along the trace of the Buffalo Fork thrust.

The evidence that the western part of the Mount Hancock block was tilted west and that the northern extension was tilted north has been discussed. These relations and attitudes are interpreted as being the result of downdropping of these segments against the East Sheridan and Heart River faults, rather than uplifting of the main mass of the Mount Hancock block. Additional evidence of stability of this block, also admittedly only suggestive, is that it is not nearly as shattered by faults as are the exposed parts of the Basin Creek uplift to the west and the Washakie Range to the east.

Probably the strongest evidence of stability of the main arch of the Wolverine-Hancock anticlinal complex southsoutheast of Mount Hancock, and evidence supporting the interpretation that the Huckleberry Ridge Tuff on Mount Hancock is approximately at its original level of deposition with respect to sea level, is provided by the regional distribution of the tuff. It is present on both east and west flanks of the anticlinal complex and if this had been uplifted 2,000 (or even 1,000) feet in postrhyolite time, the folding would have had to be domal and compressional (yet bounded on three sides by tensional faults), with the apex east of Mount Hancock. This amount of folding should be noticeable as a disruption of the old Laramide anticlinal crest and in subsidiary structures to the southsoutheast. No evidence of a new generation of modification was found.

When the base of the Huckleberry Ridge Tuff is structure contoured along the east side of Jackson Hole for 25 miles south of Yellowstone National Park, the contours trend almost due north, reflecting only the hinging down of Jackson Hole along the Teton fault that bounds the east margin of the Teton Range. Eastward projection of the acquired dips would put the base of the tuff far above 10,000 feet, on Mount Hancock, even allowing for slacking off of the dip and for reconstruction of the rhyolite base prior to subsequent movement along the intervening Sheridan fault complex. Had Mount Hancock been raised 2,000 feet in postrhyolite time, one would expect the structure contours to swing east, south of the park boundary, but they do not.

If the assumption is correct that the Huckleberry Ridge Tuff on Mount Hancock is approximately at its original level of deposition with respect to sea level, then the correlative unit on Mount Sheridan probably was at an initial elevation of about 10,500 feet. This would put the base of the Heart Lake Conglomerate at about 10,200 feet. The highest part of the Basin Creek uplift, at the headwaters of the stream that deposited the conglomerate, probably was a few miles to the northwest and may easily have had an elevation of 10,500–11,000 feet. Adding another 1,000 feet of rhyolite, which is about the thickness now present on Mount Sheridan, the crest of the uplift, and, presumably, the lip of the caldera directly to the north, may have had an elevation of as much as 12,000 feet before both began to collapse in late Quaternary time.

An uplift of the inferred size and elevation of the Basin Creek feature is not only significant from a standpoint of Quaternary tectonics and volcanism, but it also probably had an effect on climate and ice accumulation during part of Pleistocene time.

Such large-scale Quaternary tectonism as has been demonstrated or postulated certainly had a profound influence on the drainage patterns in southern Yellowstone National Park. The most conspicuous effects, previously described, are the zig-zag course of the Snake River, the

ponding of some streams, the abandoned channelways of streams that were diverted by faulting or warping, and the steep, sharply delineated canyons of the Lewis, Heart, and Snake Rivers (fig. 3). To a considerable extent, these canyons were cut after the last ice occupied the sites.

SUMMARY

The prevolcanic structural features in southern Yellowstone National Park are of large amplitude and regional extent. The Laramide features—Washakie Range, Basin Creek uplift, and Wolverine-Hancock anticlinal complex—are parts of a major system of tectonic elements; these originally continued northward and were later covered by the volcanic rocks of the central region of the park. The Laramide elements are similar, both in type and trend, to structural features along the north margin of the park (Ruppel, 1972), and, in fact, the upwarps may have once been connected or have been en echelon. Regardless of the exact relations, however, there is little doubt that the present site of Yellowstone National Park, at the close of Laramide deformation, was a region of basins and uplifts very similar to those that are now exposed to the north, south, and east. This structural and physiographic terrane was then modified by many episodes of volcanism and tectonism in late Tertiary and Ouaternary times.

The Quaternary episodes are especially significant to the location and nature of thermal features, patterns of glaciation, and major drainage changes that were responsibile for cutting of the Snake, Heart and Lewis River canyons. Indeed, the uniqueness of Yellowstone National Park may in large part be attributed directly to its underlying structure and to its complex tectonic history. Still unanswered is the fundamental question as to why this specific region within the Rocky Mountain chain was the center of such prolonged volcanism and tectonism that began in Cretaceous time and has continued to the present.

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